PHYSICS BY EXPERIMENT

SHAW

compels throughout the use of the hands together with the use of the mind. Please observe, too, that it gives specific directions in method of performing the experiments.

General Features.

It will be seen that after each experiment the principles are stated inductively, or with the term of the definition last. In the Summary they are stated deductively, or with the term of definition given first. The Questions and Problems make a wider application of the principles, and suggest their manifold application in a greater degree than can be done in the text proper.

The whole subject of *Sound* will be found particularly clear and condensed in its treatment. It will be found, upon observing the results generally attending the study of physics, that the treatment of sound leaves the student more confused than any other subject. Please note the development of *Intensity* and *Pitch* by the use of the home-made "siren," page 308, and the "stretch-string," page 157. A large number of questions and problems in Sound are given, because the thought they call for extends the pupil's knowledge of the subject.

The subject of *Electricity*, except frictional electricity, is based upon the idea of the "lines of force." It was not until electricians began to deal with the lines of force, and to base all their experiments upon this theory, that the great development in the practical use and application of electricity was made. A distinguishing characteristic of this book is its clear, carefully graded, and logical development of the subject of voltaic electricity. Teachers in Grammar and High schools, who have heretofore been so much embarrassed in teaching voltaic electricity, will appreciate this feature.

Experiments.

Experiment 88 illustrates the simplicity of nearly all the apparatus the student is called upon to make.

Experiment 88 is an example of a great number in the book, which the student can perform by himself, the conclusions reached being afterwards tested by questions from the teacher in class.

Experiment 87 is one of another class of experiments, which the student is obliged to perform and to explain without direct help being given him. It is, however, but an application of knowledge that he has previously gained.

Sp[illegible]endix.

Among the many New Features of Physics by Experiment we would direct attention to the following:

The treatment of the *lever* and the development of the law of the lever.

The treatment of the *Screw*, and the practical application given on page 26.

Experiment 42, Figure 40.

Experiments 48, 49, 56.

The development of the principle in the Hydrostatic Press, Experiments, 59, 60, and 61. Heretofore the subject of the Hydrostatic Press has not been made clear in text-books. The pupil has taken for granted what was said, but he has not seen why it was so. The explanation of the way that leakage is prevented in the Hydrostatic Press as shown in Figure 71,—a matter which proves extremely interesting to pupils.

Experiment 66, Figure 76.

Experiment 67 shows another feature of the book—the student being helped up to a certain point and then forced to think out the rest for himself.

In *Pneumatics*, Experiment 73 and the test under it, as well as Experiment 74 and the test following that.

Experiment 78, for the development of Mariotte's Law.

On page 118 the comparison of the readings of different thermometers. Experiment 88 also is new.

Figures 111 and 112 show an old law by a new, simple, direct, and forcible way.

Experiment 109 shows, as nothing but the apparatus can show, how a steam-engine works.

Experiment 140 upon Shadows; Experiments 141 and 142 to show the intensity of light.

Experiment 144 is another illustration of a piece of apparatus that all students can make and use.

The construction required in Figures 155 and 156.

Total Reflection, Experiment 156.

Figure 162, page 191, requiring of the student, in order to complete the figure, a thorough knowledge of what has been shown in Figure 161.

Figure 177, giving a clearer treatment of an old illustration.

Experiment 170, requiring the student to deal with the actual thing rather than a representation of it by lines and drawings.

In **Experiments 179, 180, and 181** the hypothesis of Polarity is so developed that any one can understand it.

Figure 219, on page 247, is not simply an explanation: the student is given the conditions, and must think out the results demanded by the questions in the text.

The application of the formula expressing Ohm's Law, pages 258 and enabling the student after reading the statement to readily apply the law solve the problems.

Figure 244, showing a piece of apparatus often but unsuccessfully attempted. Here the drawing and directions are so clear that any student can make the apparatus and secure the results.

The same may be said of the apparatus shown in Figure 247, Experiment 220. The explanation of the solenoid, page 272, is especially to be noticed.

Experiment 221, Figure 248, presents a simple and entirely new way of showing how induced currents may be generated. The Law of Induced Currents stated on page 275 has never before been given in a school text-book.

Attention is also called to the clearness of the explanation of Figure 251.

To the Experiment showing upon what principle the Telephone works, Figure 285.

To the explanation of the Dynamo, page 283.

To the Porte Lumière shown in Figure 279, Appendix; and to the Galvanometer, Figure 382, Appendix.

From a critical examination of the book it will be seen that the size of "Physics by Experiment" is disproportionate to the amount of actual knowledge to be gained from its study, because of the great suggestiveness of the work and the opportunity offered the pupil for original investigation,—a most valuable feature in any text-book, and especially one on science.

Mary Hale Woodbury
Salem, Mass.

Fall, 1897.

Physics by Experiment

AN

Elementary Text-Book for the Use of Schools

BY

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PREFACE.

Purpose.—This book is intended to lead pupils to acquire, by means of experiments, an elementary knowledge of Physics. It seeks to bring directly under the pupil's observation the reality itself, thus training him to observe for himself, to reason for himself, to rely upon himself, and to test the accuracy of his inferences and observations by new experiments, and by the comparison of his work with the work of others.

Plan.—The book is inductive in its plan, yet it is not inductive to that rigid degree that a pupil must perform an experiment, and then make the inference without being told what to look for. The experiment is first performed, then comes the statement of the law involved. In performing the experiment, however, the pupil is guided by directions and questions. He must think ; and, therefore, when he gives the statement of a principle, he has the knowledge of actual experience behind that statement.

Individual Work.—The book will be found to give large scope for individual work. Its method is believed to be in accord with Mr. Herbert Spencer's idea, that in education the process of self-development should be encouraged to the fullest extent. The plan of the book is such, that each pupil may gain his knowledge of the subject in that way of learning which is peculiar and natural to him. In other words, he comes into a knowledge of

the subject in his own individual way. It was Faraday's appreciation of the value of individual work which led him to say that he always wished to perform experiments for himself, because in this way he learned something that the description in words could not convey to him.

Mental Training.—No other subject of study in the school course gives such breadth of development to the mind as Physics ; and the knowledge of the subject which a pupil gains by experiment is a living knowledge, applicable in untold ways, which the discerning power of his training will always point out.

Scope.—This book is elementary in its character. The author concludes from his own experience, and from that of a great number of teachers with whom he has consulted, that, as a rule, text-books upon Physics are too difficult for beginners. Not until the average student has gained by experiments a knowledge of the elementary facts and laws of Physics, and acquired thereby a firm basis on which to build, is he able to take up the more abstract treatment of the subject. The author believes, as the result of his experience in the class-room, that the amount given in this book, and the method of acquiring it, will be found the shortest, the easiest, and the surest preparation to the study of advanced Physics.

Apparatus. — The experiments require no expensive apparatus. Except for the air-pump, the actual outlay for apparatus need not exceed fifteen dollars. The book, though, does not preclude the use of fine apparatus if a school possesses such an equipment. It must be remembered, however, that it is largely what the pupil does for himself that gives him interest in the subject and a love for it.

Heat and Electricity.—The chapters upon Heat and Electricity are made especially full on account of their great practical importance and interest. Small space is given to frictional electricity, as it is now regarded as of little practical importance. The dynamo is explained without reference to the Gramme ring and other complicated magneto-electric machines. Finding so many pupils confused by the explanation usually given of how electricity is generated by a dynamo, the author was led to see whether a more direct method could not be found. It is believed the one given will be found easy and direct. Greater relative space is given to voltaic and dynamic electricity, because of their constantly increasing application to such every-day needs as the telegraph and the telephone, electric lighting, electric propulsion, etc.

A year is sufficient time to devote to this book.

The author would here express his obligations for invaluable assistance in the preparation of the work to Professor Daniel W. Hering, of the University of the City of New York ; to Dr. Robert Spice, Lecturer, Cooper Institute, New York, and Professor of Physics in the Central Grammar School, Brooklyn ; to Mr. Charles E. Gorton, Superintendent of Schools, Yonkers, N. Y.; and to Mr. David E. Lain, B.S., E.E., of Yonkers, N. Y., all of whom have carefully read the manuscript. Further acknowledgments are due to Mr. Sherman Williams, Superintendent of Schools, Glens Falls, N. Y., who has kindly read the proof and made suggestions.

SUGGESTIONS TO TEACHERS.

In using this book it is necessary that the experiments should be performed. Absolute accuracy of results is not to be expected with the apparatus used; but just as great care and nicety should be taken in performing the experiments.

Remember that not every experiment will prove successful the first time. When not successful, the repetition of the experiment is the very discipline the pupil needs. It is likely that, in such a case, he has failed in observation or in manual skill, or has overlooked some important condition. Some one has happily said that an experiment that fails is often more instructive than one that succeeds.

While it is essential that the experiments should be performed, and the pupil brought face to face with the reality, this may be secured in different ways, to be determined by the teacher, who will be guided by the conditions under which he works.

The best plan is to have each pupil perform the experiments as directed in this book, and afterward to let the class witness the same experiment performed by the teacher.

Another plan is to divide the class into groups of two or three pupils, requiring each group to perform the experiments, and when a satisfactory result from a given experiment is not obtained by all the groups, to let either the teacher or the group obtaining the best result perform that experiment before the class.

Still another plan is to allow the students to perform at home the easier experiments, while the teacher performs all others before the class, requiring them to observe closely.

Require pupils to make as many drawings as possible of apparatus used in performing experiments. This leads pupils to become closer observers.

Save for future use all apparatus made.

Many teachers who use PHYSICS BY EXPERIMENT with older pupils will find it expedient to enlarge upon the text.

CONTENTS.

PHYSICS BY EXPERIMENT.

CHAPTER I.

THE MECHANICAL POWERS.

THE LEVER.

Experiment 1.—Take a piece of white pine thirteen inches long, one-quarter of an inch thick, and about three-quarters of an inch wide. Make a ruler of it by drawing marks across each end, one-half inch in from the end. Between these draw eleven other marks an inch apart. Number these marks as shown in Fig. 1. After this, cut slight notches across, on the opposite side, under each mark. The edge will appear as in Fig. 1.

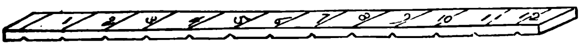


FIG. 1.

Then make a triangular prism like this :  Place the ruler on the prism, letting the edge of the prism into the notch under the six-inch mark. If one end of the ruler is heavier than the other, cut off some of the wood along the side edge of the heavier end until the ruler nicely balances.

Place a nickel* five-cent piece or a homemade weight

* A new nickel five-cent piece weighs five grams. A gram equals 15.432 grains.

(see next paragraph) over the outer mark on each end. See that the centre of the weight is on the mark. Does the ruler still balance? Move the nickel or weight from the end and place it over the three-inch mark. Does the ruler balance now? How many five-cent pieces or weights must you have on the three-inch mark to balance the one at the other end?

Procure some large shot, flatten them out with a hammer, and then cut them down with a knife until each weighs exactly the same as a five-cent piece; or take a piece of sheet lead, and cut out a square that shall weigh as much as a five-cent nickel. Having found the size of the square, mark out others on the sheet of lead and cut them out with a pair of shears. Test each one on scales (see Appendix, § 1), using the five-cent piece as a weight for each. Mark each with a figure 5. Make other weights as heavy as two, three, and four nickels, and mark each with a figure to show the number of grams each weighs. You now have a set of weights of five grams, ten grams, fifteen grams, etc.

In the experiment, how many grams at the three-inch mark balanced five grams over the end mark?

Terms.—The ruler we have been using may be called a *lever;* the triangular prism on which the lever rests is called a *fulcrum.* The five grams on the end is called the *power;* the ten grams on the three-inch mark, the *weight.*

The distance from the *fulcrum* to the power is called the *power's distance*, written *Pd;* and that from the fulcrum to the weight, the *weight's distance*, written *Wd.*

Put the fulcrum under the six-inch notch. Place twenty-five grams of weight two inches to the left of the fulcrum. How many grams must be placed five inches to the right to balance the lever?

The weight remaining the same, how many grams must be placed four inches to the right to balance the lever?

Experiment 2.—Place a weight of twenty grams three inches from the fulcrum. How many grams, as a power, placed six inches from the fulcrum, will it take to balance the lever?

Place the fulcrum under the three-inch mark of the lever. When the weight is at one end and the power at the other, how long is the *Pd?* How long the *Wd?*

Fasten to the *Wd* enough material to balance the extra wood in the long arm,* then find how many grams on the end of the lever will balance thirty grams weight.

Experiment 3.—Place the fulcrum under the two-inch mark and balance the lever. Now put fifteen grams as a weight on the end. Find the *Pd* at which five grams must be placed to balance the lever.

Results of the Experiments:

W.	*Wd.*	*P.*	*Pd.*	*W.*	*Wd.*	*P.*	*Pd.*
10	3	5	6	20	3	10	6
25	2	10	5	30	3	10	9
10	2	5	4	15	2	5	6

* In all experiments with the lever, it is necessary that it should balance before comparing the weight and the power.

Can you determine, by examining the results as set down on the bottom of p. 11, the relation that exists between the *W* and *Wd* on one arm of the lever, and the *P* and *Pd* on the other arm of the lever ?

Problems.

A man with a crowbar 6 feet long places a stone for a fulcrum 1 foot from the end. If he presses down on the other end with a power equal to 150 pounds, what weight can he raise ? 750

Make a drawing to represent this lever.

If with the same crowbar the fulcrum is placed 6 inches from the end, what weight can the man raise with a power of 150 pounds at the other end ?

With the same bar and power, what weight can be raised when the fulcrum is 8 inches from the end ?

Lever of the First Class.—In all our work with the lever so far, the fulcrum has been placed between the weight and the power. Such a lever is called a *Lever of the First Class.*

Review.—*A Lever* is a bar of any kind turned on a rest or pivot.

The Fulcrum is that on which the lever rests or turns.

The Power is the force applied to one part of the lever.

The Weight is the body to be moved or balanced by the application of the Power.

The Power Arm is the part of the lever between the fulcrum and the power.

The Weight Arm is the part of lever between the fulcrum and the weight.

A lever of the First Class is one where the fulcrum is between the power and the weight.

PRINCIPLE.—The product of the Power by the Power-distance always equals the product of the Weight by the Weight-distance.

Hence: 1. $W = \frac{P \times Pd}{Wd}$. 2. $Wd = \frac{P \times Pd}{W}$.

3. $P = \frac{W \times Wd}{Pd}$. 4. $Pd = \frac{W \times Wd}{P}$.

Lever of the Second Class.—We have already learned that when the fulcrum is placed between the power and the weight we have a lever of the First Class.

Let us now study a lever where the fulcrum is at one end, the power at the other, with the weight between the two.

Experiment 4.—Place a weight two inches from the fulcrum. Raise it by applying the finger, as in Fig. 2.

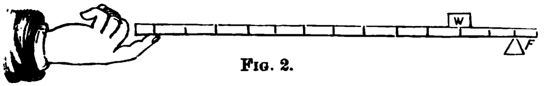


Fig. 2.

Place the weight over the six-inch mark, Fig. 3, and raise it with the finger as before.

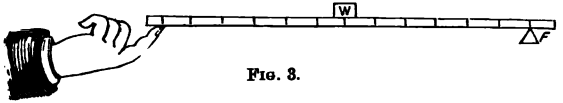


Fig. 3.

Place the weight over the ten-inch mark, as in Fig. 4.

Use the same weight each time. When does the weight

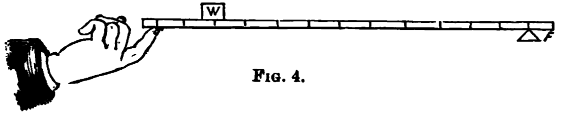


Fig. 4.

seem the heavier, when it is nearer the power or when nearer the fulcrum? In which position, then, does it require the least power to lift a given weight, when the weight is near the power or the fulcrum?

In the lever of the *first class* the power and the weight move in opposite directions. In what direction do they move in a lever of this class?

Let us now see if the same principle will apply to this class of levers.

Experiment 5.—First, take another ruler thirteen inches long, like the one used in Exp. 1. In the mark one-half inch from the end drive two pins, leaving the heads a quarter of an inch from the wood. Balance this lever on a triangular prism, and place the two rulers as in Fig. 5.

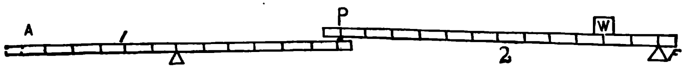


FIG. 5.

As there are six inches on each side of the fulcrum in the ruler marked 1, the downward pressure at *A* will produce an equal upward pressure at *P*. We use lever 1 merely to change the direction of the power.

Place enough weight at *A* to balance the wood of lever 2.

Place thirty grams two inches from the fulcrum. How many grams must be placed at *A* to balance it? The upward pressure at *P* being equal to the downward pressure at *A*, we call the *Pd*, the distance from *P* to *F*, the same as in the lever of the First Class, and the *Wd*, the distance from *F* to *W*.

Prove from the above experiment that the $P \times Pd = W \times Wd$.

Experiment 6.—Place the thirty grams over the four-

inch mark. Do we need more or less power now to raise it? How many grams of power are needed? Does the principle stated on page 12 apply here?

Lever of the Third Class.—Thus far we have studied two classes of levers.

Levers of the First Class, *F* between *P* and *W*. The *P* and *W* move in opposite directions. Levers of the Second Class, *W* between *P* and *F*. The *W* and *P* move in the same direction. There is one more class of levers. In this class the power is between the weight and the fulcrum.

Drive a tack into the ruler used in Exp. 1, a half inch from the end, and drive another tack into a board. Tie a short piece of string to each tack. This will act as a fulcrum, and a lever will be formed, as shown in Fig. 6.

Put the weight at the end and raise the lever by putting the finger directly under the weight. Move the finger towards the fulcrum. Does the weight appear to grow heavier or lighter?

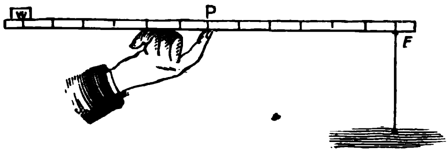


FIG. 6.

As the power in a lever of this class is applied in an upward direction, we shall have to use a lever, as we did in Exp. 5, to change the direction of the power.

Experiment 7.—By means of lever *a b* apply a power of ten grams at *c*, six inches from *F* of the upper lever, as shown in Fig. 7, and find what weight will be balanced at *W*.

Caution.—Be careful to fasten enough material at *S* to

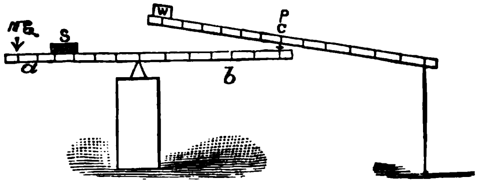


FIG. 7.

balance the wood of the upper lever, before attempting Exp. 7. Can you tell why it is necessary to do this?

Experiment 8.—Apply a power of thirty grams three inches from the fulcrum; what weight will be balanced nine inches from the fulcrum?

In levers of the First and Second Classes the weight was always greater than the power. How is it in levers of the Third Class? Does the principle learned in levers of the First Class apply to levers of the Third Class? Let us see. In Exp. 7, the *W* is 5, *Wd* 12, and the product is 60. The *P* is 10, *Pd* 6, and the product is 60. The products being equal, the principle applies.

Law of Levers.—This principle, then, applies to all three classes of levers; and as these three classes comprise all possible cases of simple levers, we may call it a *General Principle or Law of Levers.*

Advantages Derived from the Use of the Lever.—Suppose a man wishes to move a weight of three hundred

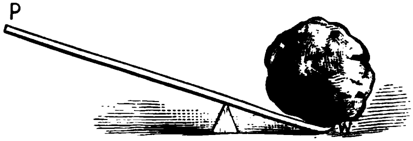


FIG. 8.

pounds, but can move only one hundred and fifty pounds unaided. If he takes a bar as in Fig. 8, he can move the weight with its aid. What has he gained? Has he gained force? It

seems so. But notice, Fig. 9, how far the power has to move from *a* to *c* in order to raise the weight the short distance from *b* to *d*. It will take a great deal longer to raise the weight up to a level with *a* than it would if the man were able to lift three hundred pounds instead of one hundred and fifty.

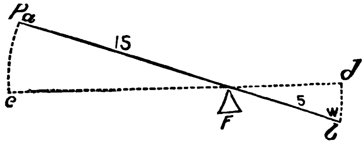


Fig. 9.

So if we gain force, there is a corresponding loss in *time*.

You will find this to be the case also in levers of the Second Class, Fig. 10.

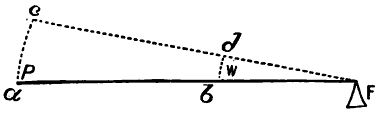


Fig. 10.

In the Third Class lever there is an apparent loss of force because the power is greater than the weight, but we see from what we learned concerning the other two classes that the loss in force is balanced by the gain in time; for while the power is moving from *a* to *c*, the weight is moving all the distance from *b* to *d*, Fig. 11.

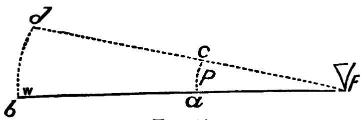


Fig. 11.

Review Questions.

In which class of levers is the *Wd* a part of the *Pd*?

How does a common thumb latch on a door represent two classes of levers? Which two classes are they?

In which class of levers is the *Pd* part of the *Wd*?

Classify the following as levers: a pair of sugar tongs, a lemon-squeezer, a pair of scissors.

Give two new illustrations of each of the three classes of levers.

In which class is the weight never less than the power? In which class is the power always more than the weight? 3

Problems.

1. What weight can be lifted by a lever of the First Class with a power of 250 pounds, the *Wd* being 8 inches and the *Pd* 4 feet? 1560

Make a drawing of this lever.*

2. A lever of the First Class is 5 feet long. A man wishes to raise a weight of 950 pounds. He places the fulcrum 9 inches from the end. What power is required? 167 $\frac{7}{11}$

Make a drawing of the lever.

3. What weight can be raised with a lever of the Second Class when the *Wd* is 9 inches and the *Pd* 3 feet 3 inches and the power 225 pounds? 975

Make a drawing of the lever.

4. What kind of a lever is an oar, when one is rowing a boat? What advantage is gained by a lever when the *Wd* is greater than the *Pd*? Time

When the *Pd* is greater than the *Wd*? Power

THE FIXED PULLEY.

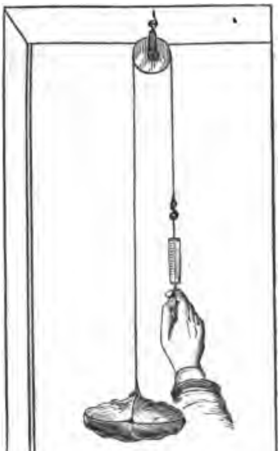


Fig. 12.

Experiment 9.—Take a stout cord and tie it to a stone weighing about sixteen pounds. Weigh the stone with a spring-balance. Procure a pulley about two inches in diameter, which may be had at any hardware store. Fasten or screw the pulley into the casing. Oil the pin of the pulley to lessen the friction as much as possible. Pass the end of the string over the pulley, and then fasten it to the hook of the spring-balance, as in Fig. 12. Raise the stone by pulling down on the spring-

* All illustrative drawings should have their parts in proper proportion.

balance. How many pounds does it require to raise the stone? What advantage have you gained by the use of the pulley?

Mark the casing at *W* and also at *P*, as in Fig. 13. Pull slowly and steadily on the spring-balance, and raise the stone to *w*, as in Fig. 14. Mark the casing again at *w* and *p*. While raising the stone, notice how many pounds are indicated on the spring-balance. Notice also how many pounds are indicated to keep the stone suspended without motion.

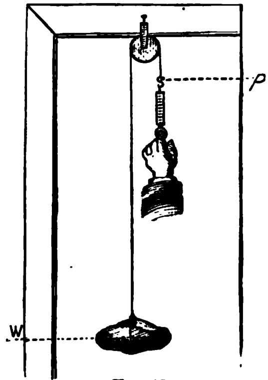


Fig. 13.

While the stone is being raised, the force required to lift it is a little greater than the force needed simply to balance the stone.

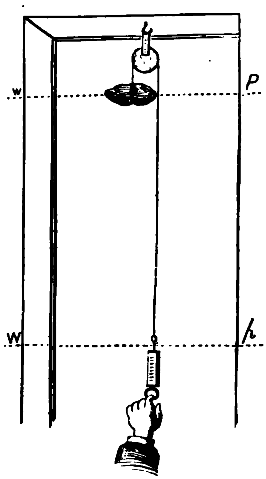


Fig. 14.

Friction.—We shall find it true of *all* machines that some force is wasted when *motion* takes place. The wasted energy or force is required to overcome the resistance caused by the rubbing together of the different parts of a machine when in motion. Such resistance is called *Friction.* In the lever the amount of friction at the fulcrum is so small that we did not have to consider it in our experi-

ments. In some machines, however, it becomes so great that it is a hindrance to their usefulness.

Friction is a resistance to motion. When a ball is rolled on ice, it goes farther than when rolled on a wooden floor; farther when rolled on the floor than when rolled on a carpet; farther on a carpet than when rolled in the sand. Its rotation is stopped in each instance by friction. The greater the amount of friction, the sooner the ball stops.

Name other instances of friction.

THE MOVABLE PULLEY.

Experiment 10.—Put a screw-eye into the casing. Fasten the pulley to the stone used in the previous experiments. Tie one end of the cord to the screw-eye, pass the cord through the pulley, and raise the stone with a spring-balance, as shown in Fig. 15.

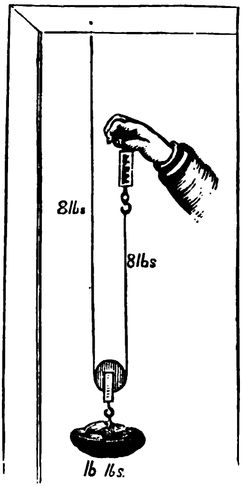


FIG. 15.

How many pounds of power does the spring-balance indicate? How does the power compare with the weight?

Raise the stone exactly two feet. Measure the distance through which the power passes.

Is the $Pd \times P$ equal to the $Wd \times W$? Why, while raising the stone, does the spring-balance show the application of more force than is required to suspend the stone while at rest?

Advantage gained by the Use of the Movable Pulley.—In the experiment with the fixed pulley, we found that the power passed through just the same distance as the weight. The advantage gained was the change in direction of moving the power.

In the experiment with the movable pulley, we find that the power moves twice the distance that the weight moves. It takes twice as long to raise the weight with the movable pulley as it did with the fixed pulley, but it requires only about half the power used in that experiment. Why, then, does the movable pulley reduce the power one-half ? This will be readily understood from the following explanation, which refers to Fig. 15. If the weight were fastened to one string, that string, of course, would support the whole weight of sixteen pounds. Notice, however, that there are virtually two cords supporting the weights, the one fastened to the screw-eye, the other to the spring-balance. As the weight of sixteen pounds is sustained by two cords, it is plain that each cord sustains one-half of sixteen pounds, or eight pounds.

Combination of a Fixed and a Movable Pulley.—Fig. 16 is a representation of a movable and fixed pulley combined. The only advantage such a machine has over the preceding one is that by the introduction of fixed pulleys the direction of the power is changed.

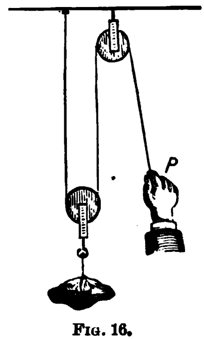
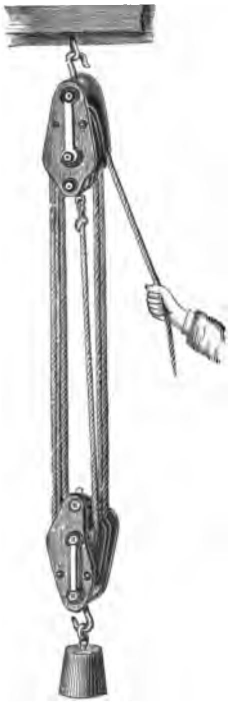


FIG. 16.

THE BLOCK AND FALL.

The block and fall may be explained from what has been learned about pulleys by Fig. 17. The weight of eighteen pounds is sustained by six cords, hence each cord bears three pounds. We have noticed that power is gained

by the use of movable pulleys, and that difference of direction only is gained by the use of fixed pulleys.



18 lbs

FIG. 17.

In Fig. 17 the power is three pounds, the weight eighteen pounds. You will notice that there are six cords supporting the movable block.

Then the weight eighteen divided by six, the number of cords supporting the movable block, equals three pounds, the power.

In Exp. 10, the weight is sixteen pounds and the power is eight pounds. There are two cords supporting the movable pulley. The weight, sixteen pounds, divided by two, the number of cords supporting the movable pulley, equals eight pounds, the power.

With movable pulleys having a continuous cord, the power multiplied by the number of parts of the cord supporting the movable block equals the weight.

THE WHEEL AND AXLE.

The wheel and axle in its simplest form is shown by Fig. 18. The cylinder on which the rope winds is the *axle*, and the part to which the power is applied is the *wheel*. The wheel and axle is a modified lever of the First Class. The two circles in Fig. 18 represent the circumference of the

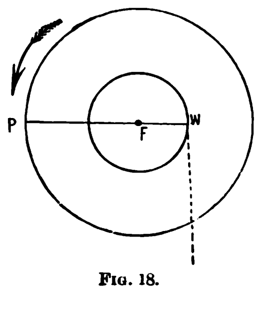


FIG. 18.

axle and of the wheel. The line *P F W* shows the lever. *F* is the fulcrum, and at the same time the centre. The distance from *F* to *W* is the short arm of the lever, or *Wd.* The distance from *F* to *P* is the long arm, or *Pd.* If the distance from *F* to *W* is four inches, and that from *F* to *P* ten inches, what weight can be raised with a power of one hundred pounds?

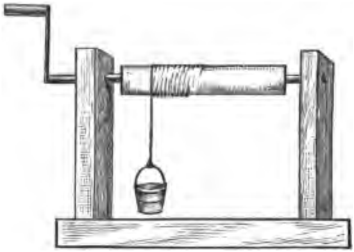


Fig. 19.

Other forms of this machine are shown in Fig. 19, the *windlass*, and in Fig. 20, the *capstan.*

Fig. 20.

THE INCLINED PLANE.

Example of an Inclined Plane.—A man by aid of a long plank can roll a barrel of flour into a wagon, which he could not put in by means of his own strength. A plank so used is an *inclined plane.*

Experiment 11.—With a piece of board three feet long, a roller skate or a small toy car, fit up a piece of apparatus like that in Fig. 21. Raise the end just one foot high by using crayon boxes and flat pieces of wood. Place upon the car a weight of ten or twelve pounds. Oil the wheels to reduce the friction to the least possible amount. Attach one end of a cord to the car, and the other to a spring-balance. Draw the weight up the inclined plane,

keeping the cord always parallel to the plane. Note how

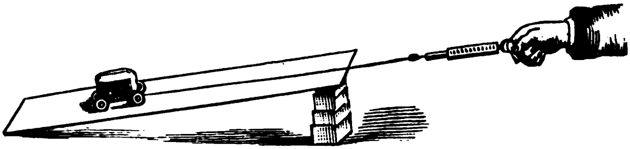


Fig. 21.

many pounds of force it requires to draw up the weight. Write down the results under the following heads :

Length of Plane, or *Pd*.	*P*.	Height of Plane, or *Wd*.	*W*.
3	4	1	12

Raise the end of the plane up to one and one-half feet, and see what force is required to move the weight. 5

Write down the results under their proper heads.

Raise the plane to a height of two feet and find the force required to move the weight. 8 Write down the results. Lower the plane to a height of one-half foot and find the force required to move the weight. 2 Write down results.*

Fig. 22.

Can you discover the law of the inclined plane when the power acts parallel to the plane?

THE WEDGE.

The wedge is a machine used for splitting and rending asunder where great power is required. In Fig. 22 you will notice that the parts of the wood have been pressed apart by the wedge. If the wedge is three inches thick, how far has the wood been pressed open? and if the wedge is

* A small allowance must be made for friction.

twelve inches long, how far is the force moved that drove the wedge? Now the driving apart of the pieces of wood is the work to be done; and if the work to be done has passed through three inches of space, and the power through twelve inches of space, how much less power will be required than the amount of work done, not allowing for 1/4 friction? Give three instances of the use of the wedge.

THE SCREW.

Experiment 12.—Cut a piece of paper in the form of a right-angled triangle, as in Fig. 23. It will be noticed that the upper side *A* is an inclined plane. Wind the paper around a lead-pencil, as in Fig. 24.

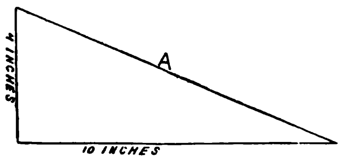


FIG. 23.

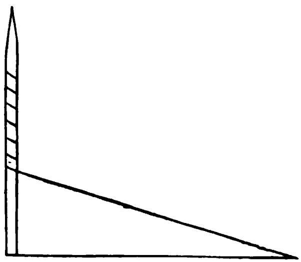


FIG. 24.

Can you follow the inclined plane from the base to the top?

An inclined plane wound round a cylinder is called a Screw. The elevations are called threads.

The screw works in a *nut*, which has threads on the inside. The nut may remain stationary and the screw move in it, or the screw may remain stationary and the nut move.

Experiment 13.—Cut out of paper two right-angled triangles of the size given in Fig. 23. Form two screws

by winding the triangles in opposite directions around two lead-pencils, and fastening the end of the paper with a little mucilage. The threads of the two screws thus formed run, you will notice, in opposite directions. One is a *right-hand* screw; the other, a *left-hand* screw.

Put the balls of the thumb and first three fingers to-

gether to form a temporary *nut*. Take a common screw and, by turning it, propel it into the nut formed by holding the balls of the fingers together. To send this screw forward, you will notice that the right hand must be turned from you.

Now select the right-hand screw from the two made of paper.

Take the left-hand screw and with the left hand propel it into a *nut* formed by holding the balls of the thumb and fingers of the right hand together.

To send the screw forward you will notice that the left hand must be turned from you.

Tests.—Take a common carriage bolt and nut. Hold the nut in the left hand. Which way must you turn the bolt to drive it into the nut? Hold the bolt in the left hand. Which way must you turn the nut to send it up on the bolt?

Is the screw by which the burner of a kerosene lamp is fastened to the bowl a right- or a left-hand screw? Which way must you turn this screw to screw on the burner? Which way to take it off? Why do the screws on the right-hand end of wagon axles have right-hand threads, and those on the left-hand end have left-hand threads? Why must a turn-buckle have a right-hand and a left-hand thread?

SUMMARY.

There are six Mechanical Powers: The Lever, the Pulley, the Wheel, and Axle, the Inclined Plane, the Wedge, and the Screw.

There are three kinds of Levers:

First Class, with the Fulcrum between Power and Weight.

Second Class, with the Weight between Power and Fulcrum.

Third Class, with the Power between Weight and Fulcrum.

Principle of Levers: $P \times Pd = W \times Wd$.

There are two kinds of Pulleys:

1. The Fixed Pulley—Advantage, a change of direction.
2. The Movable Pulley—Advantage, a gain in force with a loss in time.

The Block and Fall is a combination of fixed and movable pulleys.

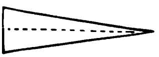
Principle of the Block and Fall:

The $W = P \times$ the number of cords supporting the movable block.

Principle of the Wheel and Axle: The radius of the wheel $\times P =$ the radius of the axle $\times W$.

Principle of the Inclined Plane: Length of the plane $\times P =$ height of plane $\times W$.

The Wedge consists of two inclined planes placed base to base as shown in the sketch.



There are two kinds of Screws: Right-hand and Left-hand Screws.

Friction is the resistance a body meets from the rubbing of its surface by the surface on which it moves or the medium through which it passes.

Questions and Problems.

1. What kinds of levers are involved in the treadle of a sewing-machine? 3
2. State the general law of the lever.
3. Name the three important points of the lever.
4. To what class of levers does the wheelbarrow belong? 2
5. What kind of lever is shown in Fig. 25? In Fig. 26? In Fig. 27? 1
6. What kind of a lever is the fore-arm when raising a weight held in the hand (Fig. 28)? 3
7. The length of a lever of the Second Class is 5 feet, the weight 250 pounds, and the fulcrum 21 inches from the weight. What power is required to lift the weight?

8. A uniform beam 12 feet long and weighing 48 pounds is supported at both ends, and sustains a weight of 250

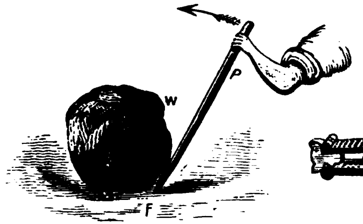


FIG. 25.

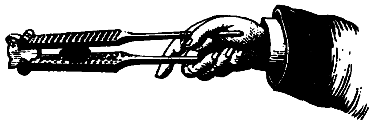


FIG. 26.

62½ 187½ + 24

pounds at a distance of 3 feet from one end. Find the pressure on each point of support.

FIG. 27.

9. What kind of a lever is shown in the steelyard (Fig. 29)?

10. What kind of a lever is a claw-hammer, when used to pull a nail out of wood?

11. A block and fall has four sheaves in the upper pulley and four in the lower, with rope fastened to the lower part of the upper pulley. What power is required to hoist 2,000 pounds? 250

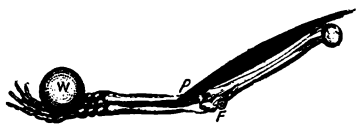


FIG. 28.

12. In Fig. 18, p. 22, the diameter of the axle is 8 inches, and the length of the crank 13 inches. How much power is required to draw up a bucket of water weighing 70 pounds?

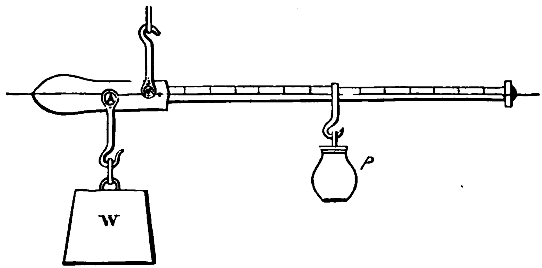


FIG. 29.

13. The capstan, Fig. 20, is 11 inches in diameter, and each of the

sailors pushes with a force of 250 pounds, 2½ feet from the centre. What weight can they draw in ?

14. What power must a man exert to roll a barrel weighing 300 pounds up a plank 7 feet long, into a wagon 3 feet high ? 128 4/7

15. Mention three common applications of the inclined plane.

16. An inclined plane is 50 feet long, and rises one inch to the foot. What power is required to draw a ton up the plane, not allowing for friction ? 166 2/3

17. How many tons of force must be exerted at *A* to raise the weight of 12 tons (Fig. 30) ? 6

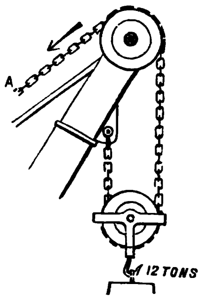


Fig. 30.

18. A nut-cracker has a nut placed 2 inches from the hinge. The hand exerts a pressure of 3 pounds, 5 inches from the hinge. What is the pressure upon the nut ? 7 1/2

19. A man has to roll a barrel weighing 800 pounds into a wagon 4 feet high. He can lift but 150 pounds. How long a plank must he use for an inclined plane ? 21 1/3

20. A windlass has an axle 1 foot in diameter, and a crank 3 feet long. What power must be exerted on the crank to lift 1,000 pounds ? 166 2/3

21. Two boys, weighing respectively 90 and 60 pounds, have a plank 12 feet long. In playing see-saw, where must the fence-rail upon which the plank turns be placed so that the plank will balance, the boys sitting at the opposite ends of the plank ?

22. A common door-key is what kind of lever ?

23. Which way does the thread of a right-hand screw slant ?

24. Which way does the thread of a left-hand screw slant ?

25. A block and fall has three sheaves in the lower block, and four in the upper block, with the rope fastened to the lower block. What power is required to raise a long ton, adding 20 per cent. for friction ?

26. Cut off a strip ⅛ inch wide along the hypotenuse of the paper triangle used in Exp. 12. Wind this strip around a lead-pencil, and you have formed a square-threaded screw. How many threads are there to the inch ?

27. How many threads (V-shaped) were there to the inch on the common screw you used in Exp. 13 ?

CHAPTER II.

MATTER.

THE MOLECULE.

Experiment 14.—Put in a warm place two tumblers of cold water, one containing water from the well and the other water that has been boiled. Let them stand an hour or two.

What do you observe clinging to the inner surface of one of the tumblers?

Where did they come from?

Were they in the water before it was put into the tumbler?

Why are they not found clinging to the inner surface of both tumblers?

Experiment 15.—Fill a tumbler or a test-tube brimful of water, and then slowly sprinkle into the water as much finely powdered salt or sugar as possible without running the water over.

What becomes of the salt?

Experiment 16.—Procure a piece of glass tubing about nine inches long, with a bore three-quarters of an inch in diameter. Stop one end with a cork and support the tube upright. Take a bottle or test-tube holding fully an ounce, measure it exactly full of water and pour it into

the glass tube. Measure out exactly the same quantity of water and pour that into the glass tube. Make a scale by drawing, with a lead-pencil, lines a sixteenth of an inch apart, upon a piece of paper two inches long and one-quarter of an inch wide. Number every five divisions of the scale, 5, 10, 15, etc. Paste the scale upon the glass tube so that the line marked 15 shall indicate the height of the water, and empty the water from the glass tube.*

Now measure exactly the bottle or test-tube full of alcohol and pour it into the glass tube. Measure the same quantity of water and pour this into the glass tube with the alcohol. Observe carefully what takes place, and note by the scale the height of the mixture.

How can you account for what you have observed?

Experiments that have been made.—The strength of a cannon is tested by forcing water into the bore. When the pressure becomes very great, small drops of water appear on the outside of the cannon. This water has been pressed through the iron, which proves that there are spaces or interstices between the particles of iron, though these interstices cannot be seen even by means of the most powerful microscope.

In the eighteenth century some Italian scientists made hollow globes of silver, filled these with water, and placed them in a screw-press. The globes flattened, which diminished their size. Water, however, collected on the outer surface, which proves that the particles of water are smaller than the interstices between the particles of silver.

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* A graduated grain-glass with a capacity of one thousand grains can be used instead of the tube.

Minuteness of the Particles of Matter.—All matter is supposed to consist of exceedingly small particles separated from each other by spaces. So small, indeed, are these particles that we cannot conceive of their size. The following statement will give some idea of their minuteness:

The perfume of a rose will fill a large room. Millions of particles must be thrown off from the rose to fill the room so completely ; yet if the rose is weighed with the most sensitive scales when it is brought in, and weighed again after the room is filled with perfume, no loss of weight can be discovered. If the rose be carried from room to room until its perfume is distributed through the whole house, we cannot find that the rose has lost any weight. How exceedingly small, then, must these particles be, if millions upon millions of them are thrown off from the rose without any perceptible loss of weight !

The Molecule.—All bodies are made up of exceedingly small particles called *Molecules,* and every molecule is separated on all sides from those around it by inconceivably small spaces.

The smallest particle of matter that can exist independently of other particles is called a Molecule.*

Experiment 17.—With an ignition-tube, a rubber cork, and a piece of bent tubing (see Appendix, §2), fit up a piece of apparatus as shown in Fig. 31.

Put a small quantity of red oxide of mercury in the ignition-tube and heat it.

* Sir William Thomson concluded that if a globe of water the size of a football were magnified to the size of the earth, the molecules would each occupy spaces greater than those filled by small shot, and less than those occupied by footballs.

Let a few bubbles of the air in the test-tube escape, and then place over the mouth of the bent tube which is under water an inverted test-tube filled with water. As the bubbles of gas rise in the test-tube, the water will be driven out. When all the water has been driven out, cork the test-tube while its mouth is still under

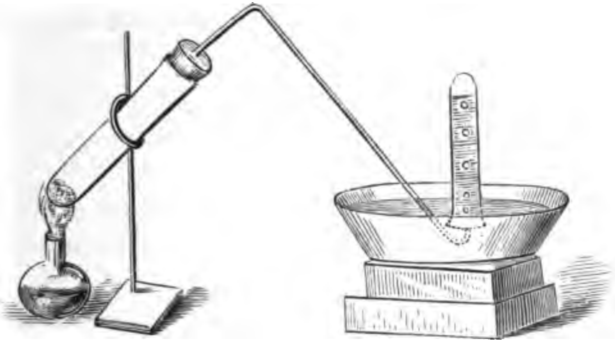


FIG. 31.

water. Collect in the same way another test-tube of gas, and remove the flame. With the mouth of the test-tube up, remove the cork, and plunge into the tube a small piece of pine stick which you have previously held in the flame just long enough to produce a small spark upon the end.

Observe the result. Would the same effect be produced were the test-tube filled with air? Notice what has collected on the inner surface of the ignition-tube.

The red oxide is made up of molecules; but we have just seen that by means of heat the oxide was destroyed, and in its stead two substances were obtained—oxygen and mercury. What two substances, then, were combined to form each molecule of the red oxide?

The Molecule not the Smallest Division of Matter.—As the smallest particle of the red substance is called a molecule, and this molecule is composed of two substances, it is plain that a molecule can be divided.

When, however, the molecule is divided, the substance is changed or separated into the elements which compose it.

The particles which compose a molecule are called Atoms.

How does a molecule differ from an atom?

Of what substances were the atoms which composed the molecules of the red oxide used in Exp. 17?

Physical and Chemical Changes.—The subject of Physics does not deal with the phenomena of substances beyond the molecule.

The study which deals with the breaking up of molecules into their atoms is called Chemistry.

A change in a substance which does not break the molecule is a Physical change, and a change in which the molecule is resolved into its atoms and new molecules formed is a Chemical change.

Experiment 18.—Put a piece of ice in a pan upon a stove. What takes place if the stove is hot? Is it a physical or a chemical change that takes place?

Dissolve some salt or sugar in a test-tube of water. Evaporate the water by boiling. What remains in the test-tube? What kind of a change took place?

When sugar is dissolved in water, what is the change?

Melt a piece of lead and pour it into a mould. Wherein is the piece of lead obtained like, and wherein different

from the original piece of lead? Was the change physical or chemical?

Put some sugar upon a hot stove. What is left? What kind of a change has taken place? Dissolve sugar in a tablespoonful of water until a thick syrup is formed. Heat the syrup and add two or three drops of sulphuric acid. Note the change. What kind is it?

Give five examples of each kind of change.

Experiment 19.—Press a thin piece of blotting paper down into a funnel. Then pour some muddy water in the hollow formed in the paper, and place the funnel in a bottle.

What is the difference between the water in the funnel and the water in the bottle?

As there are no holes in the paper, how does the water get through?

You remember what was said under Molecules about water being pressed through iron. Can water pass through wood?

Why do toy balloons become smaller the longer you keep them?

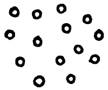
How does water pass through flower-pots when there are no holes in them? It must pass through the interstices between the molecules, or pores, as they are more properly called.

The pores of most bodies are so small that they cannot be seen. Such pores are called *insensible* pores.

MOLECULAR FORCES.

Experiment 20.—From previous study you know that the molecules of a body do not touch one another. This

sketch will represent the relation they bear to one another.



Take now a piece of rubber and stretch it out to twice or thrice its original length. How does the position of the molecules when the rubber is stretched differ from their position before the rubber was stretched? Let go the rubber. Why do the molecules regain their former position?

Take a rubber eraser and press it together end-wise. In what position are the molecules now as compared with their former position? Remove the pressure. Why do the molecules assume their former position?

Let a marble fall upon a smoothing-iron. Let a steel or iron rod and a narrow strip of wood fall end-wise upon the smoothing-iron. At the instant these strike, the marble is a trifle flatter, and the rod of steel and the strip of wood are each a little shorter; but the molecules push apart to assume their original position, and the marble, the rod, and the stick rebound.

The Forces Existing between Molecules.—These experiments show that between the molecules of bodies there exist two forces — one tending to draw the molecules, when disturbed, back to their original position, the other tending to push the molecules back to their original position when crowded together.

Example of the Action of Attractive and Repellent Forces.—Bend a thin strip of wood as shown in Fig. 32.

When let go, the stick straightens. What force is acting between the molecules along the side *A*? What along the side *B*?

If the stick is bent too far, the molecules are separated

beyond their power of attraction for each other, and the stick breaks.

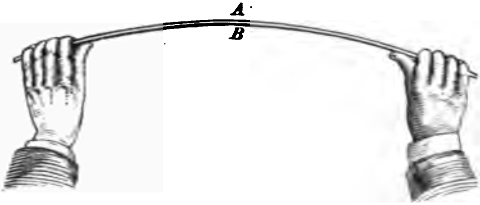


FIG. 32.

Questions.

1. What is a molecule ?
2. What is an atom ?
3. What is a physical change ?
4. What is a chemical change ?
5. What are insensible pores ?
6. Why is a piece of oak stronger than a piece of pine of the same size ?

PROPERTIES OF MATTER.

Everything that occupies or takes up space is Matter.

Examples of matter : Wood, stone, air, water.

Experiment 21.—Take a stone, a piece of wood, and a piece of lead. Can each of them be weighed ? Lay them on a hard surface, and strike each one several times with a hammer. Is the effect upon the wood and the stone the same as that upon the lead ? In what respect are these three substances alike, and in what respect do they differ ? In what respect are water and oil alike, and in what respect do they differ ? Wherein are a piece of glass and a piece of copper alike, and wherein do they differ ?

All matter has certain qualities which are called the *properties of matter.*

Those qualities that are possessed by all matter in common are called General Properties of matter.

Those qualities that are possessed by some kinds of matter and not by others are called Specific Properties of matter.

Extension.—Can you think of any particle of matter so small that it does not take up any space? Or can you think of any particle of matter that does not have the three dimensions, length, breadth, and thickness?

That property of a body by virtue of which it occupies space is called Extension or Magnitude.

Is Extension a general or a specific property of matter?

Experiment 22.—Fit a rubber cork tightly in a lamp chimney, and press the open end down into a vessel of water. Why does the water not rise in the chimney and fill it?

Fill a bottle full of water and place it in a saucer. Drop into the bottle small stones. Why does the water overflow as the stones are dropped in?

The water does not fill the chimney, because the chimney cannot be full of air and contain water at the same time.

When a nail is driven into a piece of wood, the nail presses the wood aside before it can enter.

That property of matter which prevents two bodies from occupying the same space at the same time is called Impenetrability.

Is impenetrability a general or a specific property of matter?

Experiment 23.—Take a lump of sugar and crush it in

the hand. You have divided it into a multitude of little grains. Each grain is a little lump of sugar; and with a hammer you can crush it in turn, until you have ground all to the finest powder. Yet each particle of the powder will still be sugar, and will contain a great many molecules of sugar. If each grain of sugar dust be divided into its molecules, we still have sugar. If, however, the molecules be again divided, the portions are no longer sugar, but are atoms of different elementary substances that combine to form the molecules of sugar.

That property of matter by virtue of which a body can be divided into minute particles is called Divisibility.

Is divisibility a general or a specific property of matter?

Experiment 24.—Weigh carefully a piece of wood, and then burn it. Weigh the ashes that remain. A large part of the wood appears to have been destroyed. Such, however, is not the case. The molecules of wood have been broken up into the atoms of which they are composed. Those atoms that are gaseous have gone off into the air; those that remain are solids which we call ashes. If we could weigh the gaseous parts and the ashes, we should find nothing lost. No matter what change is produced in a substance, not a single atom is lost to the universe. Matter cannot be destroyed.

That property of matter by virtue of which it cannot be destroyed is called Indestructibility.

Is indestructibility a general or a specific property of matter?

Porosity.—In studying about molecules you learned that the molecules which compose a body are separated by spaces much larger than the molecules themselves. Cold water can be forced through iron, as may be seen when hydraulic presses are worked. Francis Bacon took a shell of lead, filled it with water, and exerted great pressure upon the shell; the water was forced through the lead, and collected, like dew, on the outside of the shell. Mercury has been forced through wood and through leather. Wood and unglazed earthenware will absorb water. Water itself will absorb air. Gold will absorb mercury.

The property a body has of possessing spaces or pores between its molecules is called Porosity.

Though some bodies possess this property in a much larger degree than others, yet we may call it a general property of matter.

Experiment 25.—Obtain a long, slim cork that fits well into the neck of a bottle, and grease the cork to make the bottle air-tight. Press the cork down into the neck of the bottle. Notice that although no air can escape between the glass and the cork, you are still able to press the cork a considerable way into the neck of the bottle. How does the distance between the molecules of air when the cork is pressed down compare with the distance between the molecules before pressure was put upon the cork?

Fill the bottle with water and make the experiment again. Why this difference?

That property of matter by which a body can be forced to occupy a smaller space is called Compressibility.

This property is a general property of matter, but different bodies possess it in different degrees. Liquids possess it to a very small extent, while gases are very compressibie.

Elasticity.—In the last experiment you observed that when you removed the pressure on the cork the air in the bottle forced the cork back to its former position. A tightly twisted string, if let go, will resume its former shape by untwisting. A piece of whalebone, if bent and then the force removed, will instantly spring back to its former position.

That property a body has of resuming its former shape after some applied force has been removed is called Elasticity.

Elasticity results from the action of molecular forces.

Experiment 26.—Take a piece of wood, a strip of leather, a piece of copper wire, and a piece of iron wire. Let each be of the same diameter, and about a foot long. Fasten each securely at one end, and in any convenient manner suspend a weight at the other end. Increase the weight. Which is pulled apart with little weight? Which requires the most weight to pull it apart.

When the attractive force between the molecules of a body offers much resistance to any attempt to pull the body apart, the body is said to possess the property of Tenacity.

Steel and iron are good examples of tenacious bodies.

Experiment 27.—With the end of a broken file see if you can make an indentation in a piece of window-glass by pressing and working the broken end of the file on the surface of the glass. Try in a similar way to make an indentation in wood with a piece of glass.

When the molecules of a body are so strongly held in position that ordinary pressure does not displace them, the body possesses the property of Hardness.

Experiment 28.—Heat a piece of glass tubing in a flame. When hot pull gently upon the glass. It is drawn out into a wire. Take a piece of copper wire six feet long. Fasten one end, and pull carefully at the other. Measure the wire afterwards. It is longer. Iron and other metals are drawn into wire when cold by pulling them through the holes in a draw-plate.

The property some bodies possess, which enables them to be drawn out into wire, is called Ductility.

Iron, steel, heated glass are substances which possess this property. Gold is the most ductile metal. Silver, platinum, iron, and copper come next, in the order given.

Experiment 29.—Exert pressure upon a piece of crayon or a strip of glass, as you did upon the stick (Fig. 32). The crayon and the glass break.

A body that will not stand much distortion without being fractured possesses the property of Brittleness.

Experiment 30.—Place a shot or a small lead bullet upon a piece of iron, and hammer it until it is very thin. It has become a sheet of lead. Place a small piece of antimony upon the iron, and hammer it. It flies to pieces at the first blow.

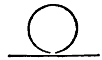
A body that can be hammered or rolled into sheets possesses the property of Malleability.

Gold is the most malleable metal.

Questions and Problems.

1. What is the difference between a general and a specific property of matter? Give three examples of each.

2. An ivory ball is let fall from a height of six feet upon a slab of marble. Let the sketch represent the ball and the surface of the marble just before the ball strikes. Make a similar drawing to show the shape of the ball and the surface at the instant the ball strikes. Give reasons for the effect shown in your drawing.



3. Is there any proof that the dense metals, gold and silver, have pores?

4. A piece of flint will scratch glass; which is the harder body?

5. If you strike a small piece of the metal antimony with a hammer, it will be crushed into a powder. What property of matter does it lack?

6. Write the names of all the properties of matter, placing the general properties in one column and the specific properties in another.

7. After each property write the names of three substances, not already mentioned, which possess that property.

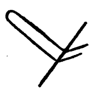
THE THREE STATES OF MATTER.

Experiment 31.—Let us put on the table a stone, a glass of water, and an empty glass, which, of course, is filled with air. These represent the three conditions or states in which matter exists. The stone is matter in a solid state, the water is matter in a liquid state, and air is matter in a gaseous state.

Can you take up one part of the stone without taking up the whole? Can you take up a part of the water without taking up the remainder with it? Turn the stone over. Have the molecules changed their position in relation to one another? Pour the water into another glass. Have the molecules changed their position in relation to one another?

A body whose molecules are held so firmly together that the body tends to preserve a definite volume and shape is a Solid.

Experiment 32.—Put a cork, not too tight, in a bottle, and place this under the receiver of an air-pump. Exhaust the air. When the air is partly exhausted from the receiver, the cork will fly out of the bottle, and part of the air that was in the bottle will come out and diffuse itself throughout the space under the receiver. Did the molecules of air in the bottle change their position of relation to one another as the cork flew out? Fill the bottle with water and cork it as before. Place the bottle under the receiver and exhaust the air. Does the water flow out of the bottle and diffuse itself throughout the receiver?

Experiment 33.—Bend the ends of a hair-pin up so as to form a rest for a sewing-needle, thus:  With this, place a needle on the surface of a glass of water. Hold another needle of the same size vertically above the water, with its point as near the surface as possible without touching. Let go the needle.

State what takes place. Can you explain it?

With the bent hair-pin, place two needles on the surface of the water half an inch apart. Put carefully upon the water between the two needles a drop of alcohol.

State what takes place.

A body whose molecules easily change their relative positions, yet tend to cling together, is a Liquid.

What is a Gas?—Suppose we had placed the bottle of air used in Exp. 32 under a receiver twice as large; the air, when the cork flew out, would have filled the whole

receiver. No matter how large the receiver might be, the air escaping from the bottle would fill it.

A body whose molecules tend to separate from each other to an indefinite extent is a Gas.

How Matter may be changed from one State to Another.— Ice is a solid. Apply moderate heat, and what does it become? Apply still greater heat, and to what state is the water changed? What caused the ice to become a liquid? What will cause lead to become a liquid? What zinc?

By more intense heat liquids can be transformed into gases.

Steam, a gas, is reduced to the liquid state by cooling it.

Water, a liquid, when made sufficiently cold becomes ice, a solid.

Pressure, also, aids in transforming bodies from gases to liquids and from liquids to solids. Steam under great pressure becomes a liquid at a much higher temperature than it does without such pressure. Carbonic acid gas when subjected to pressure and intense cold becomes a solid.

To change matter, then, from a gaseous to a solid state, what agencies may be employed?

How are these agencies employed in transforming matter from a solid to a gaseous state? Heat lead—what is the effect? Heat water—what is the effect? Freeze it—what is the effect? Heat crystals of iodine in a flask—what is the effect? In each of the above instances, what state is the body in before the experiment, and what state after?

Experiment 34. — Dissolve saltpetre in boiling hot water; set the solution aside to evaporate slowly. Dissolve blue vitriol in hot water, and set it aside to evaporate. Examine these after evaporation.

Make a concentrated hot solution of saltpetre. Pour it on a clean pane of window-glass. What is the result?

In certain kinds of matter, the molecules will arrange themselves in some regular order, if allowed to move freely in coming together to form a solid.

Substances which form crystals are called Crystalline bodies.

Alum, salt, cast-iron, and snow are crystalline bodies.

Substances which do not crystallize are called Amorphous bodies.

Chalk, glue, and glass are examples of amorphous bodies.

Cohesion and Adhesion.—Two pieces of polished plate glass can be laid so close together that they will become one solid mass. For this reason, mirror manufacturers exercise great caution not to lay the surfaces of mirrors together.

If two pieces of wax be pressed together they become one piece. The molecules are brought near enough together for the attractive force to act.

The attractive force which exists between molecules of the same kind is called COHESION.

Two pieces of wood are often held together by glue; pieces of porcelain by cement.

The force which holds together molecules of different substances is called ADHESION.

Adhesion and Cohesion Arbitrary Terms.—The distinction between Cohesion and Adhesion is one made for convenience and not because it is essential. We have no right, for instance, to say that the force holding molecules of wood to molecules of glue, is different in kind from that holding molecules of glue together.

Experiment 35.—Place in a glass of water several pieces of glass tubing having their inner diameters of different sizes (Fig. 33). How does the height of the water in the tubes compare with its height in the glass. Compare the height of the water in the larger tube with its height in the smaller. Make a sketch of the tubes representing the comparative height of the water in each, and the form of the surface in each, and outside of each.


FIG. 33.

Dry the tubes and place them in mercury. Make a sketch showing the heights to which the mercury rises and the form * of the surface in each tube and outside it.

Experiment 36.—Take two oblong pieces of clean window-glass, stand them vertically in a shallow dish of water. Notice the form of the surface of the water between the plates, and where the water touches the outer side of the plates.

Separate the plates at one edge, putting a cork between the edges. Tie a string around the plates to hold them as in Fig. 34. Stand the inclined plates vertically in a shallow dish of water. Notice the form of the surface of the water between the plates.

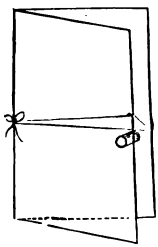


FIG. 34.

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* If zinc tubes were used, the mercury would rise in them as water does in glass tubes.

The tendency of liquids to rise in small tubes, or to be drawn up against surfaces they wet, is called Capillary Attraction.

Experiment 37.—Fill an ounce bottle nearly full of water. Add as much salt to the water as it will dissolve. When the water has dissolved as much salt as it will, it is said to be *saturated.* Color the brine in the bottle with red ink.

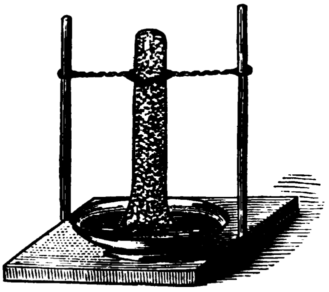

Fig. 35.

Now fill loosely with dry salt a test-tube and invert it in a saucer, as shown in Fig. 35. Pour the colored brine into the saucer and let the whole stand for an hour or so. Explain what you have observed.

Why would not colored water do as well as brine?

SUMMARY.

All bodies are composed of molecules. The molecules of a body are the smallest portions into which that body can be divided without changing its nature. All molecules are composed of atoms. The atom is the smallest possible division of matter.

There are two kinds of molecular forces, the repellent force and the attractive force.

Matter is that which occupies or takes up space.

All matter has certain qualities called the Properties of Matter. They are either General or Specific.

Some of the properties of matter are Extension, Impenetrability, Divisibility, Indestructibility, Porosity, Compressibility, Elasticity, Tenacity, Hardness, Ductility, Brittleness, and Malleability.

There are three states of matter—Solid, Liquid, and Gaseous

A solid is a body whose molecules are held so firmly together that the body tends to preserve a definite volume and shape.

A liquid is a body whose molecules easily change their relative positions, yet tend to cling together.

A gas is a body whose molecules tend to separate from each other to an indefinite extent.

Crystalline substances are those in which the molecules arrange themselves in a definite order.

All bodies that are not crystalline are called amorphous.

Capillary Attraction is the tendency liquids have to rise in small tubes or to be drawn up against surfaces they wet.

Questions.

1. What is meant by the three states of matter ?
2. In what respect does a liquid differ from a gas ?
3. In what way may many gases be reduced to a liquid condition ?
4. Explain how with lamp wicks we can place the flame so far above the oil.
5. What is a capillary tube ?
6. Define capillary attraction.
7. Explain why ink upon the edges of a book extends in farther than if spilled upon the open page.
8. Why does blotting paper absorb ink better than writing paper ?
9. Make a drawing on the blackboard to show the shape of the surface of the water when the plates used in Exp. 36 were put in a dish of shallow water.
10. Can you state any instances of capillarity not mentioned in the book, that you have observed ?

CHAPTER III.

GRAVITATION.

Attraction of Gravitation.—In the last chapter we studied the force of attraction which is supposed to exist between molecules of bodies and which acts only over insensible distances. We now come to the study of a force which acts at sensible distances.

Experiment 38.—Hold a heavy stone in the hand. A downward pressure is felt. Withdraw the hand quickly from under the stone. The stone immediately falls. In the same manner try a block of wood; a pebble. This action of the earth towards the stone and towards all other bodies is the FORCE OF GRAVITATION.

This attraction not only exists between the earth and bodies on it, but it exists between the earth and the sun, the earth and the moon, the stars and the earth; in fact, between all bodies, no matter how great or small, in the entire universe.* The force of gravitation between bodies

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* CAVENDISH'S EXPERIMENT.—This was a direct measurement of the attraction of masses for one another. Light balls were poised on a rod and their position carefully noted; large balls of lead were carefully brought near them; the light balls were attracted by the heavy masses, and their displacement measured. Great experimental precautions were necessary, such as the observation of the position of the balls with a telescope placed at a distance, the avoidance of draughts of air and of vibrations, etc.; the result showed that if lead balls had been employed as large as the earth, the attraction of such balls would have been greater than the actual attraction of the earth in the ratio

depends on two things—the quantity of matter each body contains, and the distance between their centres.

Every particle of matter in the universe attracts every other particle. This attraction is directly as the mass, and inversely as the square, of the distance through which it acts.

When bodies are free to move in any direction, they will move towards each other by means of gravitation, and when thus impelled to move towards each other both are impelled by the same amount of force. But the distance through which each of the bodies will move under the same force will be inversely as the quantity of matter in the bodies. When the earth is one body and an apple the other, we notice only the distance passed over by the apple, because of the greatness of the earth compared with the size of the apple.

The gravitation existing between the earth and bodies on it is called *terrestrial gravitation* or simply *gravity.*

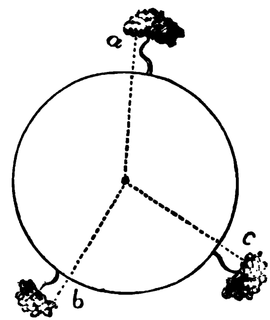

FIG. 36.

Bodies on the Earth attracted towards its Centre.—Let *a*, *b*, and *c*, Fig. 36, represent trees standing on different parts of the earth. If an apple becomes detached from the tree at *a*, it will fall to the ground in a line towards the centre of the earth. If one drop from the tree at *b* or at *c*, it will also fall in a direct line towards the centre. All bodies on the earth are attracted towards its centre.

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of 11.35 to 5.67 ; but lead is 11.35 times as heavy as water, hence the earth as a whole is 5.67 times as heavy as an equal bulk of water; or the DENSITY OF THE EARTH is 5.67.—*Principles of Physics. Daniell.*

Weight.—If a block of wood be held in one hand and a stone of equal size in the other, we notice that both are drawn towards the earth, but one with more force than the other. This downward pressure due to gravity is called *weight.*

Laws of Weight or Gravity.—I. The earth attracts all bodies towards its centre; at the centre of the earth, a body weighs nothing, because it is attracted in every direction. (See Fig. 37.)

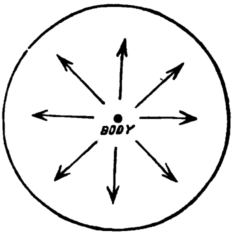

Fig. 37.

II. The weight of a body above the surface of the earth decreases as the square of the distance increases between it and the centre of the earth. The weight below the surface decreases as the distance to the centre of the earth decreases.

Experiment 39.—Tie a cord eighteen inches long to a small stone. Swing the stone horizontally just above your head. Suddenly let go the string and notice in what direction the stone flies. Try this experiment several times, letting go the stone at different points of the circle. Notice each time in what direction the stone flies. You observed that the stone flew in a straight line. Now, this straight line is always a tangent, or, in other words, it is perpendicular to the radius of the circle drawn to the point where the stone began to move in a straight line. In Fig. 38, if the stone is released at *A*, it moves in the straight line *AB*,

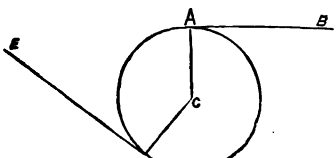

Fig. 38.

perpendicular to the radius CA. If the stone is released at D, it moves along the line DE perpendicular to CD. What keeps the stone from flying off in a straight line before it is released?

When a carriage-wheel revolves rapidly, particles of sand or mud are thrown off at a tangent.

The tendency of the stone when released, and of the particles of mud when the wheel revolves rapidly, to fly from the centre, is called the *Centrifugal Tendency.*

A body would weigh slightly less at the equator, because there the centrifugal tendency is greatest.* At the poles a body has no centrifugal tendency.

On account of the spheroidal shape of the earth, all parts of the earth's surface are not equidistant from the centre. The poles are about thirteen miles nearer the centre than the points on the surface at the equator; a body, therefore, weighs more at the poles than at the equator.

Problems.

A body at the earth's surface weighs 200 pounds. What would it weigh if put out into space 8,000 miles from the earth's surface?

SOLUTION.—The body a distance of 8,000 miles from the surface would be 12,000 from the centre of the earth,† or three times as far as it was at the surface. According to Law II., its weight decreases as the square of the distance increases. The square of 3 is 9; hence the body would weigh $\frac{1}{9}$ of 200 pounds, or $22\frac{2}{9}$ pounds.

What will the same body weigh 2,000 miles below the surface?

SOLUTION.—At 2,000 miles below the surface the body is 2,000 miles

* If the earth rotated on its axis seventeen times as fast as it does, the attraction of gravitation would only just be able at the equator to keep bodies from flying off its surface at a tangent.—*Daniell.*

† The distance from the surface to the centre of the earth is about four thousand miles.

from the centre. The distance has decreased ½, hence the body weighs 100 pounds.

What will a body which weighs 500 pounds at the surface weigh 1,000 miles below the surface? What at 3,000 miles below?

What would be the weight of a 50-pound cannon ball 4,000 miles above the surface of the earth?

A body on a spring-balance weighs 20 pounds. What would it weigh by the same balance if the body and the balance were removed 16,000 miles above the surface of the earth?

Find the weight of a body 2,000 miles above the earth's surface, which weighed at the surface 1,000 tons.

CENTRE OF GRAVITY.

Experiment 40.—Balance a ruler on the edge of a knife-blade. When it balances, mark a line by pressing it upon the knife-edge. Now stick a needle vertically into a piece of wood, and, putting the marked line of the ruler upon the end of the needle, find a point on which the ruler balances. The point above this point, half-way through to the upper side, is the *centre of gravity* of the ruler.

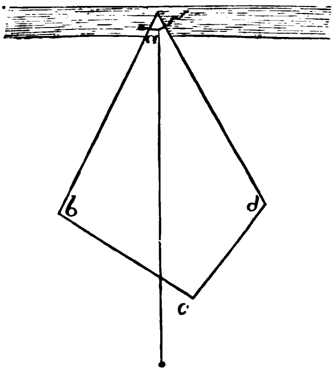

FIG. 39.

Experiment 41. — Cut out a piece of pasteboard of any irregular shape, like that, for example, shown in Fig. 39. With a small weight make a plumb-line. Prick a pin-hole *a* at one angle of the cardboard, and suspend the cardboard so that it will swing freely. Fasten

the plumb-line to the pin. When the plumb-line and cardboard are at rest, mark the direction of the plumb-line on the cardboard. Next suspend the cardboard at *b* and then at *d*, marking each time on the cardboard the direction of the plumb-line. If you have worked carefully, the three lines will cross each other at the same point. A point midway through the cardboard from this point is the centre of gravity of the body, providing, of course, that the cardboard is of the same thickness throughout.

The middle point of a body with reference to weight is its Centre of Gravity.

Experiment 42.—Cut out a piece of board of the shape and dimensions indicated in Fig. 40. Find the centre of gravity of the surface, and paste over this a circular piece of black paper *c*, one inch in diameter. At any point, say *b*, a few inches distant from *c*, paste a circular piece of red paper two inches in diameter. Now toss the piece of wood up edgewise into the air so that it will revolve rapidly. Which piece of paper moves around the other? Give reasons for what you have observed.

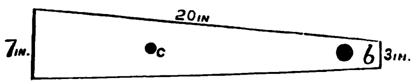

FIG. 40.

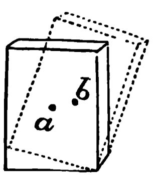

FIG. 41.

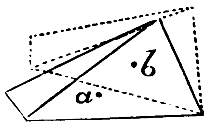

FIG. 42.

Experiment 43.—Place blocks of wood as shown in Figs. 41 and 42. The centre of gravity is at *a*. Tip the block as shown by the dotted lines, and the centre

of gravity is at *b*. Is the centre of gravity raised or lowered when the block is tipped?

When any disturbance of a body affecting the centre of gravity raises it, the body is said to be in Stable Equilibrium.

Experiment 44.—Try to stand a pencil on its point (Fig. 43). The dotted lines show it falling. Is the centre of gravity lower at *b* than at *a*? It will not stand, because any change of position lowers the centre of gravity.

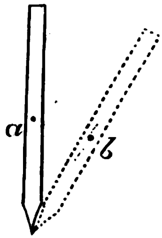

FIG. 43.

When any disturbance of a body affecting the centre of gravity lowers it, the body is said to be in Unstable Equilibrium.

Experiment 45.—Move a ball, or sphere (Fig. 44), into several different positions. Does it remain at rest in every position? Does the height of the centre of gravity change when the ball is moved?

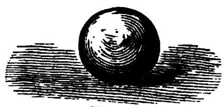
FIG. 44.

When every change of position in a body neither raises nor lowers the centre of gravity, the body is said to be in Indifferent, or Neutral, Equilibrium.

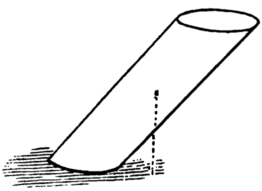
FIG. 45.

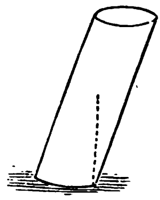
FIG. 46.

Line of Direction.—A line drawn from the centre of gravity of a body towards the centre of the earth is called the *Line of Direction*. This line is the

direction the centre of gravity of a body takes when it falls to the earth ; hence the name, *Line of Direction.* When the line of direction falls without the base of a body, it will not stand (Fig. 45). When the line of direction falls within the base, the body will stand (Fig. 46).

The stability of a body depends upon the breadth of base and the nearness of the centre of gravity to the base.

Questions and Problems.

1. In what kind of equilibrium is a sphere floating in water ?
2. A board floating on its broad side ?
3. A board when raised in water on its edge ?
4. Why is an inkstand usually made largest at the base ?
5. Make a drawing of an oblate spheroid (Fig. 47) placed in stable and in unstable equilibrium.

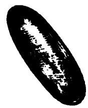

FIG. 47.

6. Make a drawing of a board, shaped as in Fig. 48, placed in stable and in unstable equilibrium.
7. Place a cone in stable and in unstable equilibrium.
8. Does the line of direction of the leaning tower of Pisa fall within the base ? (See Encyclopædia for description of the tower.)
9. Why does a person in carrying a heavy pail of water throw out the opposite arm ?
10. In what positions of equilibrium can you place a cylinder ?
11. Which is the more stable, a load of hay or a load of stone, each load weighing the same ? Why ?

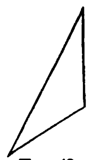

FIG. 48.

12. People unaccustomed to row-boats frequently stand upon the seats. Why are they told to step down and stand in the bottom of the boat ?
13. Give two reasons why a pyramid is a stable structure.

FALLING BODIES.

Experiment 46.—Take two stones—a small one and a large one—to a second-story window. Push both over the sill at exactly the same instant. Which one reaches the ground first ? Repeat the experiment till you are sure about the result.

Try a block of heavy wood and one of light wood. Try a stone and a feather. If the stone and the feather were let fall in a vacuum, they would reach the bottom at the same time; but the air retards the feather, because of the great amount of space occupied by a comparatively small amount of matter.

In a vacuum all bodies fall equally fast.

Uniformly Accelerated Motion.—When you let go the stone from the second-story window, it passed from a state of rest to one of motion towards the earth. Was it moving faster when it reached the ground than immediately after it was pushed from the window-sill? Was it moving faster when it reached the ground than when half way to the ground? How did the rate at which it moved when half way down compare with the rate at which it moved when quarter of the way down?

In coasting down hill, do you go faster when near the bottom, or when near the top of the hill? What causes you to go faster and faster as you descend? The falling stone, and the sled going down hill, are illustrations of *uniformly accelerated motion.*

A change of position is Motion.

Any cause that moves or stops a body, or tends to alter its state of rest or motion, is called Force.

Uniformly Retarded Motion.—*Gravity* is the force which moves bodies towards the earth. It is also the force which overcomes the motion of a stone when thrown upward until it reaches a point of rest, just before it begins to descend. The motion of a stone thrown upward is an example of *uniformly retarded motion.*

The effect of gravity acting upon a body is its Weight.

What is meant by the Term Work.—In Physics the term *work* is frequently used. Wherever motion is effected in overcoming resistance of any kind, we say that *work* has been done. When a body is set moving, stopped, or retarded in its motion, or its motion changed, *work* has been done upon that body.

The action of a force in changing the motion of a body, or in maintaining its motion uniformly in opposition to resistance, is Work.

Experiment 47.—Raise a pound weight one foot high. In doing this you have performed what is termed a *foot-pound* of work.

In raising five pounds two feet high, or in raising two pounds five feet high, *ten* foot-pounds of work are done.

Two elements enter, in measuring the quantity of work done; viz., weight and height. Time is not regarded in calculating the work done. How much work is done when two hundred pounds are raised fourteen feet high?

The amount of work expended in raising one pound one foot high against the force of gravity is called a Foot-pound.

The foot-pound is the *unit* of work. How much work is done when a bucket of water weighing sixty-five pounds is drawn out of a well thirty feet deep?

By the Momentum of a body is meant the product obtained by multiplying its weight by the number of feet through which its speed would carry it in one second.

A light body moving swiftly may have a momentum as great as a heavy body moving slowly.

The speed at which a body moves is called Velocity.

Questions and Problems.

1. When is the motion of a body accelerated ?
2. When uniformly accelerated ?
3. Give three examples of retarded motion.
4. What is meant by uniformly retarded motion ?
5. A ball is shot vertically from a rifle. It has an initial velocity when leaving the muzzle of one hundred feet per second. Is its motion in ascent uniformly retarded ?
6. What is weight ? What is force ?
7. What is work ? In what is work measured ?
8. A boat weighing eight hundred pounds is raised twenty feet in six hours by the tide. The same boat is afterwards raised twenty feet in five minutes when drawn out on a ship's davits. Was more work done in the one instance than in the other ? How much work was done ?
9. In blasting rock, one piece weighing twelve and a half pounds was thrown off with a velocity of forty-two feet per second. What was its momentum ? What its velocity ?

LAWS OF FALLING BODIES.

Moving Bodies acted upon by One Force.—The motion of a falling body is accelerated by the force of gravity. As the force is constantly exerted, the velocity constantly increases as the body falls, and the following has been found to be true : If a body starts from a state of rest, it will fall about sixteen feet during the first second of time, forty-eight feet during the second second, eighty feet during the third, and so on, as follows :

1st Second.	2d Second.	3d Second.	4th Second.
16	16	16	16
1	3	5	7
16 ft.	**48 ft.**	**80 ft.**	**112 ft.**

The total distance the body falls in four seconds is the sum of these products, which is two hundred and fifty-six feet; or, according to a principle of multiplication, sixteen feet multiplied by the sum of the multiples ($1 + 3 + 5 + 7 = 16$) = 256 ft. We may also find the total distance by multiplying sixteen feet by the square of the number of seconds: 16 ft. $\times 4^2 = 256$ ft.

The velocity at the end of the first second is at the rate of thirty-two feet per second. At the end of the second second, the motion has been accelerated to a velocity of sixty-four; at the end of the third, it is ninety-six. We see, then, that the velocity at the end of any second can be found by multiplying thirty-two by the number of seconds.

Questions and Problems.

1. A body has fallen two seconds. Were gravity to cease to act at the end of the second second, how far would the body fall in the third second?

2. Draw on the blackboard a line, and divide it into three parts to represent proportionally the distances a falling body passes over in the first, second, and third seconds. Divide the last two parts, so as to show what part of the distance passed over in the second is due to velocity, and what part is due to gravity alone?

3. How far will a stone fall in seven seconds? How far in the seventh second?

4. How long must a body fall to acquire a velocity of four hundred and forty-eight feet?

5. An arrow is shot vertically upward with a velocity of two hundred and fifty-six feet. How high will it rise? How long will it remain in the air?

6. Two stones are dropped from a lighthouse, one three seconds after the other. When the second stone has fallen two seconds, how far are the two stones apart?

NEWTON'S LAWS OF MOTION.

First Law.—A body in motion moves uniformly in a straight line unless acted upon by some outside force.

A body never changes its condition of rest or motion; all change is produced by a force outside of itself.

The inability of a body to change its own state of rest or motion is called Inertia.

Experiment 48.—On the top of a table fit up apparatus as follows: In the edge, just far enough below the upper surface to hold, drive two pins, and place on these a piece of card—one pin being at the end of the card-board, and the other near its centre, as shown in Fig. 49. Place a small marble at each end of the card-board. Next fasten a spring, a piece of whale-

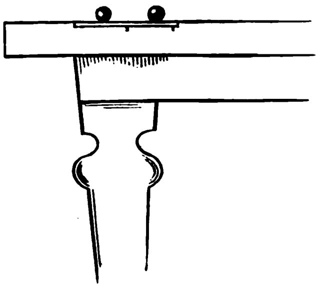

FIG. 49.

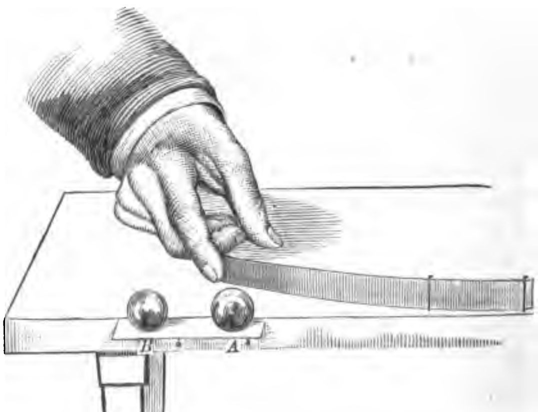

FIG. 50.

bone, or a thin strip of steel, with four nails, as in Fig. 50.

It is evident that if the marble *A* be removed, the cardboard will instantly tip, and the marble *B* will fall to the floor.

Pull the spring and let it strike *A*, sending it as far as possible. Which strikes the floor first, marble *A* or marble *B?* Did the force of gravity cause *A* to reach the floor as soon as *B?* Which fell the farther? Did *A* fall just as far and reach the floor as quickly as *B?* Did the force of gravity then act just the same on *A* as it would if the marble had merely fallen from the table?

What did the spring cause *A* to do? How far forward?

Where would *A* have gone, had not gravity acted upon it when the force of the spring sent it forward?

Second Law.—A force produces the same effect upon a moving body, or a body at rest, whether it acts alone or with other forces.

Under this law the problem of the *Composition of*

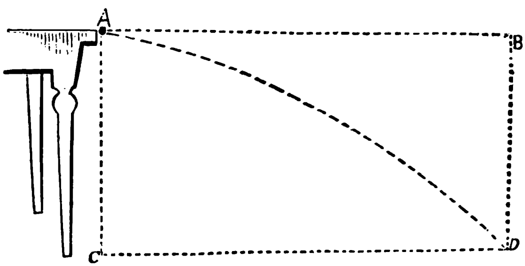

FIG. 51.

Forces is solved. In Exp. 48, the marble was driven by the force of the spring as far as *B*, but at the same time

the force of gravity drew it from *A*, as far down as *C* (Fig. 51). As a result, the marble reached neither *C* nor *B*, but stopped at *D*.

The force resulting from the combined action of two or more forces is called a ***resultant.***

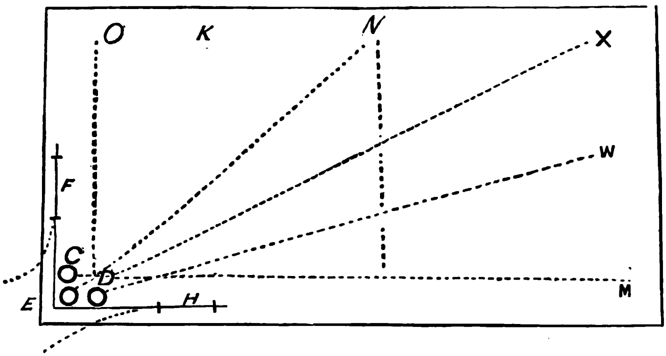

Fig. 52.

Experiment 49.—Arrange two springs, *H* and *F*, upon the top of a table, so that the ends will just clear each other (Fig. 52). Place a marble at *C*, a little way from the end of the spring *F*, in order that it may clear the nails that secure the spring *H*. Draw back *F* as indicated by the dotted lines, and let go. The marble takes the direction *C M*. Now place the marble at *D*, and operate the spring *H*. The marble takes the direction *D O*. But if we place the marble at *E*, draw back both springs an equal distance, and let them go at the same instant, the marble takes the direction *E N*, exactly midway between *D O* and *C M*. If we draw back *F* far enough to send the marble to *M*, and draw back *H* far enough to send the marble to *O*, acting together they will send the marble to *X*. If we

give *F* still greater force by drawing it farther back, and draw *H* only slightly, the marble will take the direction *E W.*

How can the marble be made to take the direction *E K?*

To find the Resultant of Two Forces.—Suppose the forces acting at right angles upon a body to be respectively of seven units, which may mean pounds or tons, and of five units. Draw a parallelogram, making one side seven units long, and the other side five units long. Draw the diagonal. The number of units in this diagonal equals the number of units in the resultant force. How many in this case? Often two forces act upon a body at a greater or lesser angle than a right angle. The angle of the parallelogram must always equal the angle between the forces. In the case above (Fig. 53), it is a right angle.

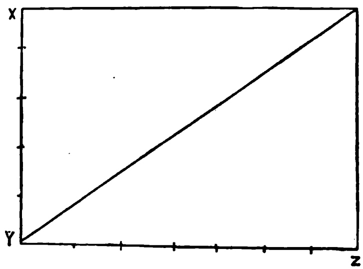

FIG. 53.

Suppose, however, the forces acted upon each other at an angle of sixty degrees—two-thirds of a right angle. We must first draw two lines meeting at an angle of sixty degrees, then making one line *A B* (Fig. 54) five units long, and the other *A C* three units long, complete the parallelogram. The

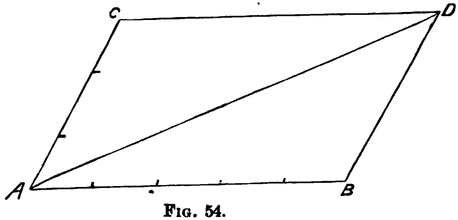

FIG. 54.

diagonal *A D*, drawn from the point where the forces acted, is the resultant.

The Resultant of More than Two Forces.—If the forces are acting at the same time, first find the resultant of two forces ; combine this resultant with a third force, and a resultant of three forces will be found. Continue in this way with the remaining forces. The last resultant will be the resultant of all the forces.

Questions and Problems.

1. State Newton's second law of motion.
2. What is inertia ?
3. How is the resultant of two forces found ? How the resultant of more than two forces ?
4. Draw a diagram representing the resultant of two forces of one hundred and twenty and one hundred and forty pounds, acting upon a body at an angle of thirty degrees.
5. Two forces, one of seven pounds and the other of eleven pounds, act upon a body at an angle of sixty degrees. Draw a parallelogram to represent these forces and their resultant.
6. Three men with three ropes attached to the same point of a log are trying to move it. The first man, standing between the other two, pulls with a force of one hundred and forty pounds ; the second man pulls with a force of one hundred and sixty pounds, at an angle of forty-five degrees with the first man ; the third man pulls with a force of two hundred pounds at an angle of thirty degrees with the first man. Find the direction in which the log will move.

THE PENDULUM.

Experiment 50.—Suspend by a string from the top of the window-casing a piece of metal. Let the point *D* (Fig. 55) be exactly midway between the two sides of the window-casing. Such an apparatus may be called a pendulum. Pull the pendulum against the casement at

A, and let it go. It moves to *B*. What force causes it to move to *B*? Does it stop at *B*? Why? What kind of motion has it from *A* to *B*? What kind from *B* to *C*? What force acts on it when it passes from *C* to *B*? Does this force act upon it all the time?

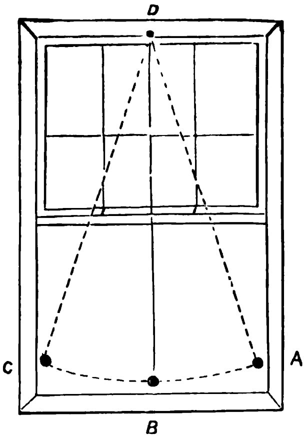

FIG. 55.

The motion from one end of its arc *A* to the other end *C* is called a *vibration*. The distance through which the pendulum travels from the lowest point *B* to the farthest point on either side, *A* or *C*, is the *amplitude* of vibration.

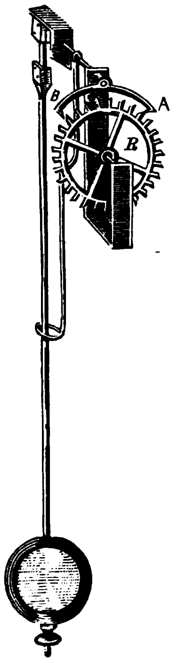

FIG. 56.

The pendulum travels from *A* to *B* to *C*, then from *C* to *B* to *A*, and so on for some time, but finally comes to rest. Why?

How a Clock Pendulum is kept Moving.—How is the pendulum of a clock kept in motion? That is, by what force is it kept moving?

Fig. 56 is an illustration of how the pendulum is used to regulate the works of a clock. The force of the main spring of the clock is exerted on the

ratchet wheel *R*, and if no hindrance were met with, the wheel would whirl around with great rapidity, until the spring's elasticity was expended.

But the prong *A* catches a tooth of the ratchet wheel. This tooth presses on the prong, and the force thus exerted throws the pendulum towards the right until the tooth slips past the prong ; at this stage, the prong *B* comes in contact with a tooth of the ratchet which presses on the prong *B*, and sends the pendulum back again to the left. In this way the pendulum is kept swinging from side to side, releasing one tooth at each swing, until the force of the spring is expended, when the clock must be wound up again.

Experiment 51.—Cut a strip of board a trifle longer than the doorway is wide ; bore three holes through with an awl, and then spring it in the doorway, as shown at *A B* in Fig. 57. Take a piece of stout cotton thread four feet long, fasten a block of wood *C* to one end, and pass the other end through the cross-piece in the door, and wedge it with a wooden pin. Make another pendulum of the same length by using a stone *D* instead of wood. Take care that the centre of gravity of the stone is the same distance from the cross-piece *A B* as the centre of gravity of the wood *C* is.

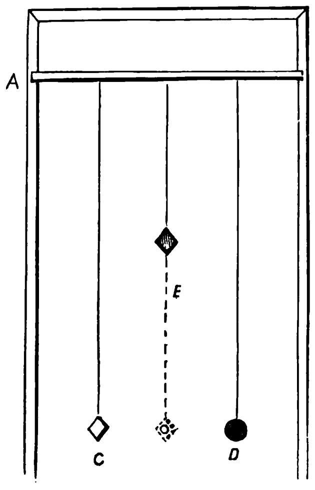

FIG. 57.

Start both pendulums at the same time, and in the same direction. Do they make the same number of vibrations in a minute? Does a change in the amount of weight at the end of a pendulum affect the time of vibration?

Let *C* vibrate through a small arc, and count the number of vibrations it makes in a minute. Then count the number of vibrations it makes through a little longer arc. Then through as long an arc as will allow the pendulum to vibrate steadily. Make the same trials with pendulum *D*. Does it make any difference in the time, whether the arc is long or short?

Experiment 52.—Take a string five feet long, and tie to the end of it an iron nut or a stone. Pass the string through the cross-piece used in the last experiment, and draw it up until it forms a pendulum equal in length to *C* or *D*. According to the facts already observed, all these pendulums will vibrate in nearly equal times. Pull up the string until you have made pendulum *E* half as long as pendulum *C* or *D*. Set it vibrating, and count the number of vibrations, or oscillations, in a minute. Has changing the *length* of the pendulum changed the time of vibration? How does the number of vibrations compare with the number of vibrations when it was twice as long?

Make it one-fourth as long as *C* or *D*, and compare the times of the vibrations.

If one pendulum is one foot long, and another four feet, their times of vibration will be compared as follows:

Length of First.		Length of Second.		Time of Vibration of First.		Time of Vibration of Second.
$\sqrt{1}$	:	$\sqrt{4}$	::	1	:	2

That is, it will take a pendulum four feet long twice the time to vibrate that it will a pendulum one foot long; a pendulum nine feet long, three halves of the time it will take a pendulum four feet long.

The time of vibration of one pendulum is to the time of vibration of a second pendulum as the square-root of the length of the first is to the square-root of the length of the second.

Length of a Second's Pendulum at New York.—The length of a pendulum that vibrates just sixty times per minute, or once each second, is 39.1 inches. This is at New York; for as gravity causes the motion of a pendulum, it follows that if the attraction of gravity changes, the vibrations of the pendulum will vary at different points on the earth's surface. If two pendulums of equal length be vibrating, one near the pole and the other at the equator, the one near the pole will vibrate the more rapidly.

Questions and Problems.

1. What is meant by the *amplitude* of a pendulum's vibration?
2. Make a drawing on the black-board, and explain with its aid how the pendulum of a clock is kept vibrating.
3. What is the length of a pendulum vibrating seconds at New York?
4. How long must a pendulum be at New York to vibrate once in two seconds?
5. A clock loses time. What is the fault with its pendulum?
6. Two pendulums are respectively sixteen and thirty-six inches long. How do their times of vibration compare?

NEWTON'S THIRD LAW OF MOTION.

Experiment 53.—Take two ivory or glass balls, and suspend them* by cords so that they may hang in contact, as shown in Fig. 58. Draw the ball *A* aside, and let it swing against ball *B*. Notice that when *A* strikes against *B*, *A* is instantly stopped, and ball *B* takes up the motion of *A*, and is moved to the point *D*. The first ball acts upon the second, imparting its motion to it, and the second ball reacts upon the first, depriving it of its motion.

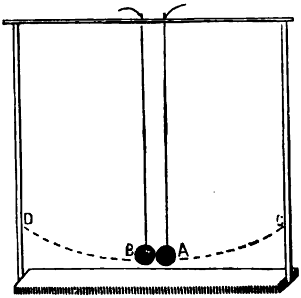

FIG. 58.

How does the momentum of ball *A*, when it strikes ball *B*, compare with the momentum ball *B* has the instant it begins to move toward the point *D*?

Third Law.—To every action there is an equal and opposite reaction. †

* These balls may be suspended by glüing a narrow strip of leather to each ball, letting the middle part of the strip project up from the ball, thus forming a loop to which the string can be fastened.

† When a shot is fired from a gun, if the gun be free to move, there is considerable recoil, the shot moving forward and the gun backwards. If the gun be fixed to the ground, the shot is apparently the only thing which moves. If the shot were held fast, and the gun were free to move, the gun would move backwards. In this case we see, then, that to the action which impels the shot forward, there is a contrary reaction which impels the gun backwards.

When a horse is loosely harnessed to a car, it may sometimes be observed that an inexperienced animal starts forward quickly; but suddenly the traces tighten, the car is jolted forward, and the horse is jolted backwards.

If a locomotive with a heavy train be suddenly started, it will be

ENERGY.

Kinetic and Potential Energy.—We have seen (p. 59) that whenever motion is effected in overcoming resistance, *work* has been done. If, then, a pendulum be raised from a state of rest at *B* to *A* (Fig. 59), motion has been effected in overcoming the resistance of gravity, and a definite amount of *work* has been done. If held at *A*, the pendulum has no motion. It has a tendency, however, to move, and is only kept from motion by the restraining power of the hand. Remove the hand ; the pendulum falls to its original position *B*, but does not stop there. It still has a tendency to move, and unless some external force is applied, it will rise to *C*. In the position *C*, also, it possesses the same tendency to move. It may be said, then, that the pendulum, when at *A* or *C*, has an ability to do work, due to its *position* ; but at *B* it has an ability to do work, due to its *motion*.

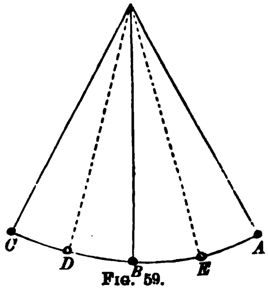

Fig. 59.

The ability to do work is called Energy.

The energy due to the motion of a body is called Kinetic Energy.

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seen that its wheels may uselessly turn round ; it has given a sudden pull to the carriages, and their reaction upon it is equivalent to a backward pull given to a moving engine.

When a stone is thrown upwards from the earth, the earth is thrown back by recoil, and moves downwards to a very small extent as long as the stone continues to ascend ; when the stone is at its highest point the earth is at its lowest, and as the stone falls, the earth ascends to meet it. This is, of course, not the result of direct observation, but is deduced by way of inference from Newton's third law of motion, which

The energy due to the position of a body is called Potential Energy.*

At *A* the pendulum has no motion, but it has energy, as it has the ability to do work. Which kind of energy, then, has it? Which kind at *C*?

At *B* it has motion, but if stopped all ability to do work is destroyed. Which kind of energy, then, has it at *B*?

At *E* it has motion, but if stopped it still has the ability to move when released. What can you say of its energy at this point?

The potential energy of the pendulum at *A* is greater than at *E*; for if it be let fall from *A*, it will do more work, i.e., move farther than if let fall from *E*. But at *E* there is a corresponding increase of motion, i.e., of kinetic energy.

The kinetic energy, then, of the swinging pendulum increases from *A*, where it is nothing, to *B*, where it is

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is confirmed by all phenomena, terrestrial and astronomical, by which it can be put to the test.—*Principles of Physics. Daniell.*

* All the forms of energy may exist in one or other of two conditions; the one an *active, motive* condition, the other a *passive* condition. In order to prevent misconception, the specific terms *kinetic* and *potential* are respectively applied to these two conditions of energy, the former being derived from a Greek word meaning *motive*, and the latter from a Latin word meaning *possible*.

Gravitation offers the most simple illustration of these two conditions. A stone falling from a height; a stream of water running, that is, falling slowly from a height; a hammer-head descending—all obviously possess active, actual, or kinetic energy, for they are capable of overcoming resistance in virtue of their mass in motion. On the other hand, a stone lodged on the face of a mountain, a clock-weight wound up, a head of water pent up in a cistern, though all actually at rest, possess, *in virtue of the very position of their masses relatively to the earth*, a potential energy which we may at any moment convert into actual. The one is as real as the other, and the one represents, and has been called into existence at the expense of a

greatest ; while the potential energy decreases correspondingly from *A*, where it is greatest, to *B*, where it is nothing.

What is the case when the pendulum swings from *B* to *C*?

The sum of the kinetic and the potential energy at any point in the arc is equal to their sum at any other point.

What is lost in kinetic energy is gained in potential energy, and the reverse.

A stone is thrown perpendicularly into the air. Which kind of energy has it the instant it leaves the hand? Which, at its highest point? Which, just before it strikes the ground? What part is kinetic energy, and what potential, when it has passed over one-third of the entire distance in its descent?

The kinetic energy of a body in motion is reckoned in foot-pounds; and is equal to one-half the product of the weight by the square of the velocity per second, divided by thirty-two; or, expressed in formula :

$$\text{K. E.} = \frac{\frac{1}{2}\,\text{W V}^2}{32}$$

Conservation of Energy.—Sound, heat, and light are forms of energy, and are mutually convertible.

Instances of this convertibility are : The energy of heat of the burning coal in the fire-box of the locomotive is converted into the energy of motion of the revolving drive-

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definite amount of the other. We cannot have actual motive energy under gravity from a body lying on the ground, or from a clock-weight run down ; it must have been raised to a height first, and have possessed the possible or potential energy. And when we do have it, it is merely the restoration of the *actual* energy which has been expended in raising the mass to a height. Thus the energy of a clock-weight shown in moving the machinery for the space of a week is merely the doling out of the potential energy imparted to it in a few seconds in winding up.—*Dr. Neil Arnot.*

wheel. In the production of the electric light, the energy of heat drives the engine ; this energy of motion is imparted to the dynamo, and changed by it into electrical energy ; this is in turn changed in the lamps to the energy of light.

The principle that the sum total of energy in all forms in the universe is always equal to a fixed quantity is called the principle of *Conservation of Energy*.

SUMMARY.

Gravitation is the attractive force which acts between masses.

Law of Gravitation.—Every particle of matter in the universe attracts every other particle. This attraction is directly as the mass and inversely as the square of the distance through which it acts.

Gravity is the attraction existing between the earth and the bodies on it.

Laws of Gravity.—I. The earth attracts all bodies towards its centre.

II. The weight of a body above the surface of the earth decreases as the square of the distance from the centre of the earth increases.

III. A body on the surface of the earth will weigh more as it approaches the poles, and less as it approaches the equator.

The Centre of Gravity of a body is the middle point of that body with reference to weight.

A body is in Stable Equilibrium when any disturbance of the body affecting the centre of gravity raises it.

A body is in Unstable Equilibrium when any disturbance of the body affecting the centre of gravity lowers it.

A body is in Indifferent Equilibrium when every change in its position neither raises nor lowers its centre of gravity.

The Line of Direction of a body is a line from the centre of gravity of that body towards the centre of the earth.

Motion is change of position.

Force is that cause which moves or stops a body or tends to alter its state of rest or motion.

Weight is the force exerted by a body, due to the effect of gravitation

Work is the overcoming of resistance of any kind.

A Foot-pound is the amount of work expended in raising one pound one foot high against the force of gravity.

Momentum is the quantity of motion a body has.

Velocity is the rate of speed at which a body moves.

Law of Falling Bodies.—Bodies fall to the earth with uniformly accelerated motion

Newton's Laws of Motion.—I. A body in motion moves uniformly in a straight line, unless acted upon by some outside force.

Inertia is the inability of a body to change its own state of rest or motion.

II. A force produces the same effect upon a moving body or a body at rest, whether it acts alone or with other forces.

The Resultant of two forces equals the diagonal of a parallelogram, whose sides represent in length the respective forces, and whose angle is equal to the angle between the forces.

A Pendulum is a body suspended so that it can swing freely to and fro.

Laws of the Pendulum —I The time of vibration is independent of the material of the pendulum, and of the length of the arc through which it vibrates.

II. The time of vibration varies directly as the square root of the length of the pendulum.

III. The time of vibration diminishes as the pendulum moves from the equator towards the poles.

Third Law of Motion.—To every action there is an equal and opposite reaction.

Energy is the ability to do work.

Kinetic energy is the ability to do work, due to the motion of a body.

Potential Energy is the ability to do work due to the position of a body.

Formula for computing kinetic energy:

$$\text{K. E.} = \frac{\frac{1}{2} W V^2}{32}$$

The principle of Conservation of Energy is that the sum total of energy in all forms in the universe is always equal to a fixed quantity.

Questions and Problems.

1. If the earth's mass were twice its present mass, with no increase in volume, what would be the effect upon one's weight ?

2. The distance between the centres of attraction of two bodies is doubled. What is the effect upon the attraction they exert towards each other ?

3. A body on the surface of the earth four thousand miles from the centre weighs four thousand pounds. If it were placed four thousand miles above the surface, what would it weigh ?

4. Suppose two bodies, ten miles apart, weighing respectively one hundred and fifty and four hundred and fifty pounds, were free to move towards each other as the result of their mutual attraction, what distance would each pass over ?

5. A body having a uniform motion passes over one hundred and fifty feet in three seconds. What is its velocity per second ?

6. A round body rolls more easily than a square body. Why ?

7. Draw a diagram on the blackboard, and explain why a ball rolls down hill.

8. How do the times of vibration of two pendulums, respectively sixteen inches and thirty-six inches in length, compare ?

9. It takes four seconds for a stone to fall from the top of a tower to the ground. How high is the tower ?

10. A cannon ball weighing twelve pounds is moving at the rate of eight hundred feet per second ; another cannon ball weighing fifteen pounds is moving at the rate of five hundred feet per second. Which has the greater momentum ?

11. Why does a steamboat continue to move after the paddle-wheels have stopped ?

12. A rifle ball shot vertically upward returns to the earth in eighteen seconds. How far did it ascend ?

13. Explain why two plumb lines are not exactly parallel.

14. A stone is let fall from a steeple. It strikes the ground in three seconds. What is its velocity per second when it strikes ? The stone weighed two and a half pounds ; what was its momentum when it struck ?

15. How far must the earth be removed from the sun that the attraction of the two bodies may become one-ninth of what it now is ?

16. Where is the centre of gravity of a ring of uniform size and density ?

17. Make a "witch" (Fig. 60) by taking a piece of elder pith *A*,

Foot-pound is the amount of work expended in raising
t high against the force of gravity.

Momentum is the quantity of motion a body has.

Velocity is the rate of speed at which a body moves.

Law of Falling Bodies.—Bodies fall to the earth wi
ccelerated motion

Newton's Laws of Motion.—I. A body in motion moves un
traight line, unless acted upon by some outside force.

Inertia is the inability of a body to change its own state
notion.

II. A force produces the same effect upon a moving body or
est, whether it acts alone or with other forces.

The Resultant of two forces equals the diagonal of a paralle
whose sides represent in length the respective forces, and whos
s equal to the angle between the forces.

A Pendulum is a body suspended so that it can swing freely
ro.

Laws of the Pendulum—I The time of vibration is independent c
naterial of the pendulum, and of the length of the arc through whi
ibrates.

II. The time of vibration varies directly as the square root of the len
f the pendulum.

III. The time of vibration diminishes as the pendulum moves from th
quator towards the poles.

Third Law of Motion.—To every action there is an equal and opposite
action.

Energy is the ability to do work.

Kinetic energy is the ability to do work, due to the motion of a
dy.

Potential Energy is the ability to do work due to the position of a
dy.

Formula for computing kinetic energy:

$$K.\ E. = \frac{\frac{1}{2} W\ V^2}{32}$$

e principle of Conservation of Energy is that the sum total of energy
l forms in the universe is always equal to a fixed quantity.

[illegible]

[illegible] Tu[illegible] [illegible] any [illegible]

[illegible]rd p[illegible] is a [illegible] k[illegible]

and gluing it to a piece of lead B (half a large shot). Explain why, when it is laid on the table, it suddenly takes an upright position.

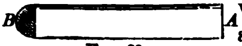

FIG. 60.

18. Explain why a pendulum vibrates. How long would a pendulum encountering no friction vibrate in a perfect vacuum?

19. How far will a body fall in the ninth second? How far in nine seconds?

20. A body weighs five hundred pounds on the surface of the earth. What would be the weight of the same body were it sunk fifteen hundred miles below the surface?

21. A ball is shot upward with a velocity of three hundred and fifty-two feet. How many seconds will it continue to rise? How high will it rise? What time will elapse before it reaches the ground?

22. Define energy.

23. How is the kinetic energy of a body found?

24. Could a bird move itself were it suspended in space, the space, except that occupied by its body, being perfectly empty?

25. A man weighing one hundred and fifty pounds ascends by the stairs to the top of a lighthouse, a distance of one hundred and forty feet. How much work has he done?

26. Find the energy of a body weighing eighty-two pounds, and moving at the rate of twenty-six feet per second.

27. What is the energy of a locomotive and tender weighing eighty tons, and moving at the rate of a mile a minute?

28. Suppose two ferryboats, each weighing a thousand tons, to collide when the first is moving at the rate of seven hundred and twenty and the second at the rate of eight hundred and fifteen feet per second. What amount of energy would be expended to crush the boats?

29. What must be the time of the rotation of the earth in order that at the equator the centrifugal tendency of bodies may just overcome the attraction of gravity?

CHAPTER IV.

HYDROSTATICS.

Experiment 54.—Tie a piece of thin rubber tissue* (see Appendix, § 3) over the mouth of a small bottle (Fig. 61). Load the bottle with a piece of lead so that it will sink. Nearly fill a glass jar with water. Place the bottle on the bottom of the jar in the water (Fig. 62). Notice the rubber covering over the mouth of the bottle. Stand the bottle up. Notice again the thin rubber over the mouth of the bottle. Turn the bottle upside down. Place the bottle in several other positions. Can you find any position in which the water does not press the rubber inward ?

FIG. 61.

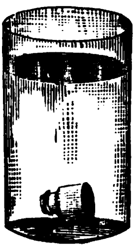

FIG. 62.

Experiment 55.—Cut out of an ordinary business-card a circular piece, a trifle larger than the large end of a lamp-chimney. Wet the end of the lamp-chimney. Put this disk over the wet end, and press the chimney down into a glass jar filled with water. What holds the disk in position? Now pour water very carefully down into the chimney. To what height does the water rise when the disk drops? Repeat the experiment, plunging the chimney to

* The rubber from a broken toy balloon is very good for this purpose.

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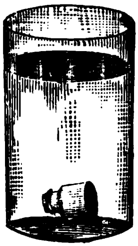

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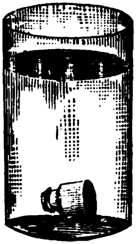

FIG. 62.

jar in the water (Fig. 62). Notice the rubber covering over the mouth of the bottle. Stand the bottle up. Notice again the thin rubber over the mouth of the bottle. Turn the bottle upside down. Place the bottle in several other positions. Can you find any position in which the water does not press the rubber inward?

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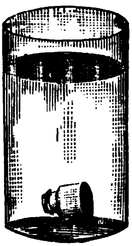

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a greater and a lesser depth. Push the chimney obliquely down into the water.

Experiment 56.—Tie a piece of rubber tissue over the end of a lamp-chimney which has been shortened (see Appendix, § 2), and to the other end of the chimney fasten a bent glass tube, as in Fig. 63. Fill the chimney with water colored with red ink, putting in enough water to rise one-third the distance to the top of the small tube. Mark on the small tube the height to which the colored water ascends. Notice that the weight of the water bulges the rubber outward.

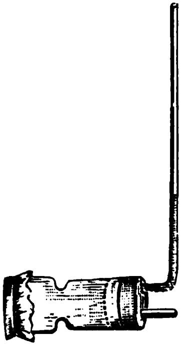


Fig. 63.

Press the rubber slightly with the finger. What is the effect upon the water in the glass tube?

Immerse the chimney in a pail of water just below the surface. Does the pressure of the water cause the liquid in the tube to rise? Put the chimney a little farther under; what do you notice as to the rising of the water in the tube? Move it down to the bottom. Where do you find the pressure of the water in the vessel the greater, near the surface or at the bottom?

Water exerts pressure in every direction, and the pressure increases with the depth.

Experiment 57.—Fill a thin glass bottle with water nearly to the top, and place a tight-fitting cork so that it just rests on the water in the neck of the bottle,

as in Fig. 64. Put the bottle upon the floor, press heavily upon the cork with a stick, and notice what happens. Do not hold the bottle while pressing.

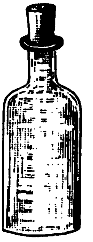


FIG. 64.

Water is only slightly compressible.

Experiment 58.—Into the small end of a lamp-chimney put a rubber cork having two holes in it. Through these holes pass short pieces of glass tubing, and over the outer ends of these fit rubber tubing, letting the rubber tubing end in pieces of glass tubing, as shown in Fig. 65. Fasten the apparatus by clamps. Now pour water into the lamp-chimney. Compare the height to which the water rises in the glass tubes with the height in the chimney.

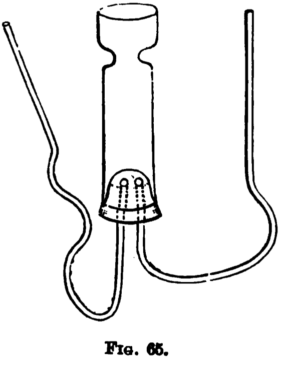


FIG. 65.

Water in pipes will rise as high as its source.

Experiment 59.—Put into the larger end of a lamp-chimney a No. 10 rubber cork (see Appendix, § 3), with a glass tube inserted, as in Fig. 66. Connect this with the tin apparatus *a* (see Appendix, § 3), by means of a piece of rubber tubing. Over each opening in the tin tie a piece of rubber tissue; suspend a lamp-chimney, as in Fig. 66, and fill the whole apparatus with water by pouring it into the small end of the chimney. Then, with the chimney brimful of water, tie a piece of rubber tissue over the

small end. Press in the rubber, and notice carefully the effect on each of the rubber coverings of the tin apparatus.

If the pressure is exerted by the finger at *A*, and the effect of the pressure is noticed at each of the coverings of the tin apparatus, what is it that transmits, or carries, the pressure from the point *A* to each of the rubber coverings on the tin? What is the direction of the pressure ex-

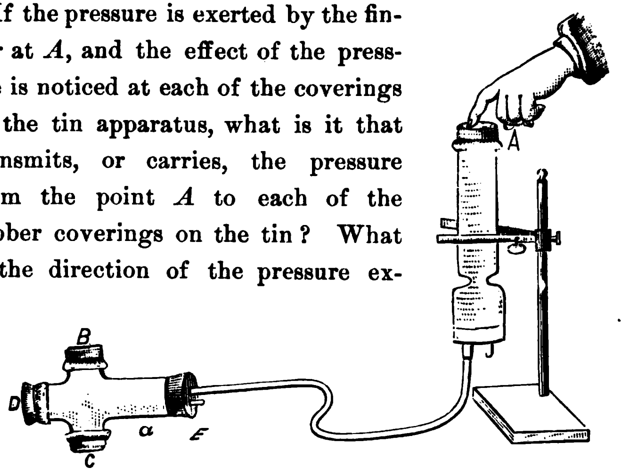


FIG. 66.

erted at *B?* What is the direction at *C?* What is the direction at *D?* What, at *E?* Is the pressure, then, transmitted by the water in all directions?

Water transmits pressure equally in all directions.

Experiment 60.—Take out the rubber cork at *E*, and allow all the water to flow out of the apparatus. Replace the cork again at *E*. Now press in the rubber at *A*. Did the rubber at *B*, *C*, and *D* again show the effect of the pressure of the finger?

In Experiment 59, we found that water transmits pressure in all directions. What is the substance in the tubes now that transmits the pressure from the point *A* to the different points *B*, *C*, and *D?*

We learn, then, that air, as well as liquids, will transmit pressure; but it will be found that as air is very compressible it is not so useful for this purpose as water. You discovered in Exp. 57 that you could not compress water to any noticeable extent.

Experiment 61.—Take three tubes an inch in diameter (parts of lamp-chimneys of the same size will answer), insert rubber stoppers in the bottom, and connect these tubes by bent glass tubing, as shown in Fig. 67. Secure the apparatus in an upright position by any convenient means. Pour water into one of the tubes. It will stand at the same level in all. Why? When the tubes are about half full, mark the height to which the water ascends in each.

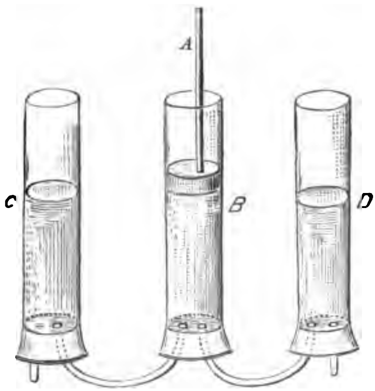


FIG. 67.

Into one of the holes of a rubber stopper that can be easily moved up and down in one of the tubes fasten a stick (see *A*, Fig. 67); close the other hole of the stopper. Now wind a strip of cotton cloth around the stopper, so that it will fit water-tight the tube *B*. Press the stopper down on the water until you have lowered the surface of the water in tube *B* one inch, and measure the height to which the water has risen in each of the tubes *C* and *D*.

If we pressed down on the surface of the water in tube *B* with a force of twelve pounds, how many pounds pressure would the water in each of the tubes *C* and *D* exert upward? Why?

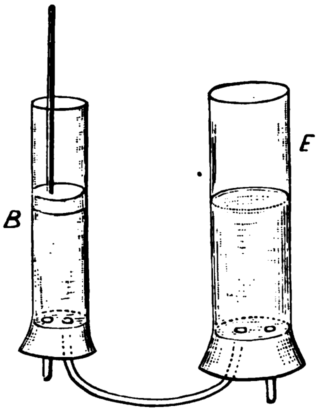


FIG. 68.

Suppose that we connect the tube *B* of Fig. 67 with one tube *E*, Fig. 68, as large as both *C* and *D* of Fig. 67. How much upward pressure will the surface of *E* exert if there is a downward pressure on the surface of *B* of five pounds?

If the stopper in *B* is pushed down two inches, how high would a water-tight stopper in *E* be raised?

The Hydraulic Press.—Hydraulic presses and jacks work upon the principles shown in Experiments 59 and 61. In Fig. 69 a hydraulic press is shown. *B* is the cylinder and *C* the piston, to the upper part of which is attached the platform. *D* is the pipe running from the force-pumps *FF*; *W* is the pipe connecting the force-pumps with the water supply. The force-pumps are worked by the eccentrics *EE* attached to the driving shaft and pulley *P*. The pulley is run by a belt. One revolution of the pulley gives one stroke of the pump. *S* is a safety-valve, and *R* is used to let the water out of the cylinder when it has been filled with water. This press is built to exert a power of 6,000 pounds to the square inch.

Why is it necessary to let the water out of the cylinder? How often must the water be let out of the cylinder?

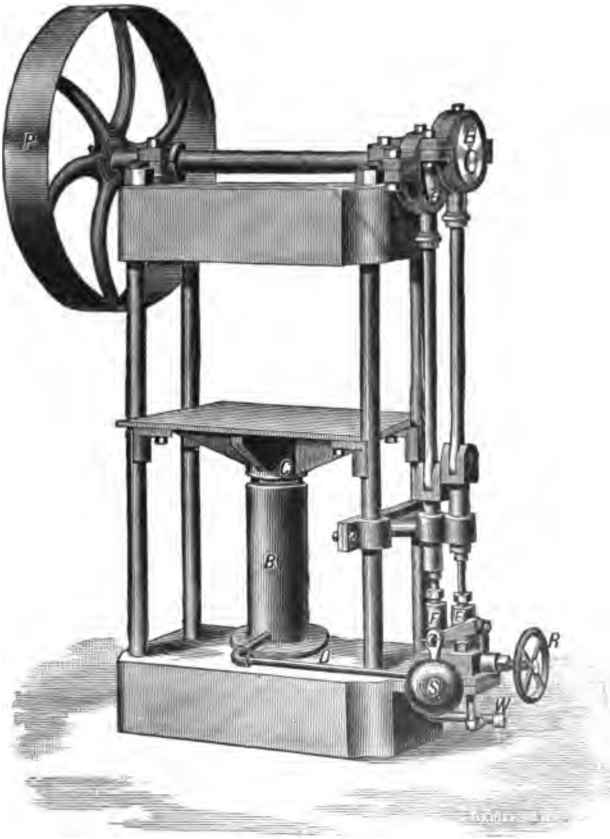


FIG. 69.

Sometimes called "Bramah's Press."—The hydraulic press is sometimes called *Bramah's Press*, because Bramah, by the invention of a water-tight collar, overcame

the leaking of water around the piston. This collar (Fig. 70) is made of leather and fits closely around the piston. Fig. 71 shows a section of the collar. *A*, *B*, *C*, *D* is a groove cut in the cylinder, in which is placed the collar. When pressure is exerted the water passes up the side of the piston and forces the lips of the leather collar in the directions *P*, *P*. The greater the pressure the more difficult it is for the water to pass beyond the collar.

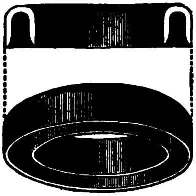


FIG. 70.

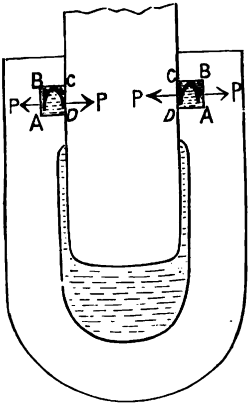


FIG. 71.

The Hydraulic Jack.—Hydraulic jacks are used for lifting. Fig. 72 is a picture of a hydraulic jack. *C* is the cylinder, *P* the piston, *F* the force-pump, worked by the handle *H*.

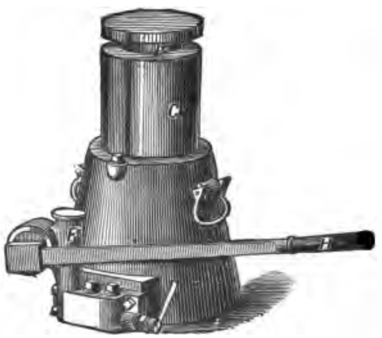


FIG. 72.

Experiment 62.—Procure a pickle or olive bottle having its mouth on the inside the same size as the large end of a lamp-chimney (*A* and *B*, Fig. 73). Procure also a glass tube *C* the same size as the large end of the chimney (Fig. 73), and about eight inches long. Remove the bottom of the bottle (see Appendix, § 2),

and grind the nozzle smooth with emery. Cut a circular piece of wood out of a piece of cigar-box, a little larger than the mouth of the bottle, and stretch smoothly over this a piece of rubber tissue. Drive a small wire staple or screw-eye into the middle point of the smooth side of the disk, and tie a string to the staple. With the straight piece of glass tubing set up a piece of apparatus, as shown in Fig. 73. Put weights on the scale-pan to hold the disk against the bottom of the tube with a little force. In addition, place on

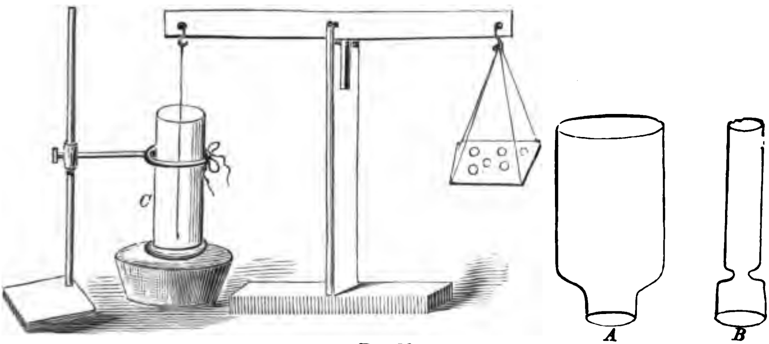


FIG. 73.

the scale-pan some definite weight, say one ounce. Now pour water carefully into the glass until the pressure on the disk causes the water to run out. Measure the height of the water above the disk just as it begins to descend.

Remove the glass tube, and put in its place the pickle-bottle. Pour in water till the disk begins to descend. Measure the height of the water above the disk. Repeat the experiment, putting the lamp-chimney in place of the bottle. Does the quantity of water influence the pressure upon the bottom. Upon what does the pressure depend?

To Calculate the Pressure of Water.—A cubic foot of water weighs one thousand ounces, or sixty-two and a half pounds. What is the pressure upon the bottom of a rectangular tank three by four feet, in which the water is two and a half feet deep? What is the pressure upon the bottom of a tank five feet square, with seventy-eight inches of water in it?

The pressure upon the side of a tank, or reservoir, is equal to the weight of a column of water, whose base is the surface pressed upon, and whose height is the depth of the water to the middle point of that surface.

How many times the weight of the water is the entire pressure upon a cubical tank filled with water?

What is the pressure upon a dam thirty feet long, with the water twenty-six feet deep?

SPECIFIC GRAVITY.

Experiment 63.—With the balance get the exact weight of a stone about the size of an egg by tying a thread to the stone. Then place a tumbler of water so that the stone hangs in it from the beam of the balance, as in Fig. 74. Weigh the stone while thus immersed. Is there any difference in the weight? Ascertain carefully these weights and their difference. Set a tumbler in a saucer, and pour water into the tumbler until it just flows over the edge. Carefully sponge up out of the saucer the water that flows over. Lower slowly into the water in the

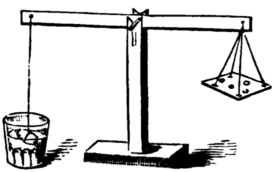


Fig. 74

tumbler the stone just weighed, and then take the stone out again. Lift the tumbler from the saucer, weigh the water which has flowed over the tumbler into the saucer, and compare its weight with the difference in weight of the stone in water and out of water.

It is, of course, very plain that the stone when placed in the tumbler displaces an amount of water equal to its own bulk. If this amount of water was exactly what the stone lost in weight when placed in water, it is also plain that the water buoyed up the stone with a force equal to the weight of the water displaced by the stone.

If the displaced water weighed half as much as the stone weighed, it is evident that the stone weighed twice as much as the water ; hence, we say the weight of this stone when compared with its own bulk of water is two, meaning that its weight is twice that of water. If the water displaced by the stone was one-fourth its weight, the weight of the stone when compared with its own bulk of water would be four. This comparing the weight of a solid with the weight of an equal bulk of water is called finding the *Specific Gravity* of that solid.

Find the specific gravity of a piece of iron. Of a piece of lead. Of a piece of glass. Of a piece of copper or brass.

Experiment 64.—Place a tumbler in a saucer, and fill it with water until it overflows a little. Carefully sponge up all the water in the saucer. Take a piece of wood containing about eight cubic inches and weigh it carefully in the air. Now with an awl or a pen push the wood

down carefully into the tumbler of water (Fig. 75).

FIG. 75.

Weigh accurately the water that overflows. How does the bulk of water in the saucer compare with the bulk of the wood?

The weight of the wood is what fractional part of the weight of the water? Or, to put the question in other words, What is the specific gravity of the wood?

Experiment 65.—Balance an ounce bottle on the scales. Fill the bottle even full of water, and weigh the water carefully. Pour out the water, dry the bottle, and fill with alcohol or oil. Find the weight of the alcohol or oil.

What part of the weight of the water is the weight of the alcohol or oil? Or, what is the specific gravity of the alcohol or oil?

It requires delicate apparatus to obtain the specific gravity of gases, hence experiments of that nature are omitted.

The weight of a substance compared with the weight of an equal bulk of some other substance taken as a standard is called its specific gravity. For solids and liquids, distilled water is the standard; for gases, hydrogen is the standard.

The specific gravity of the standard, whether water or hydrogen, is 1.

In the following table will be found the specific gravity of several important substances (at 32° F., compared with water at 39.2° F.).

SOLIDS.

SUBSTANCE.	SPECIFIC GRAVITY.
Platinum (rolled)	22.069
Gold (cast)	19.258
Lead "	11.352
Silver "	10.474
Copper "	8.788
Brass	8.383
Iron (cast)	7.207
Tin "	7.291
Zinc "	6.861
Marble	2.837
Cork	.240

LIQUIDS.

SUBSTANCE.	SPECIFIC GRAVITY.
Mercury	13.598
Sulphuric acid	1.841
Milk	1.032
Sea water	1.026
Olive oil	.915
Alcohol (absolute)	.793
Ether	.713

CARTESIAN DIVER.

Experiment 66.—Procure a small bottle two inches long and about half an inch in diameter. Fit a small cork into the mouth, and cut the cork off even so that it does not project beyond the bottle. Then remove the cork, and cut a small notch lengthwise of the cork so that by shaking the bottle slowly, after it has been filled with water, a small drop of water can be forced out. Fill the bottle with colored water and insert the notched cork. Procure another bottle about six inches long and fill with water to within three-fourths of an inch of the top. Drop

the small bottle filled with water into the larger one. If it sinks, shake out with a quick movement of the hand a drop of water. Test whether the bottle still sinks. If so, shake out another drop and try again. Repeat this till the small bottle with bottom up will just float on the top of the water (Fig. 76). Now tie tightly a piece of rubber tissue over the mouth of the large bottle. Press upon the rubber and the small bottle will move downward. Lessen the pressure on the rubber and the small bottle rises. Watch the effect of the pressure upon the water in the small bottle.

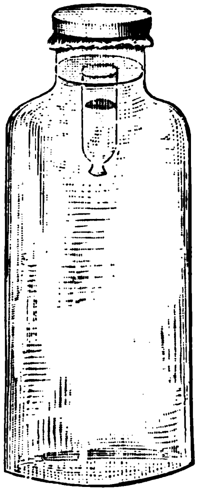


FIG. 76.

Why does the small bottle sink when you press the rubber on the larger bottle?

Cartesian Imp.—A little figure in the form of an imp, made so it would just float under the ordinary pressure of the atmosphere, was first used when this principle was discovered. This figure was made to descend and ascend through the water at will by the operator, who pressed upon some portion of the vessel containing the water, and what caused the movements of the imp, or diver, was for some time a mystery. It was supposed to be a piece of witchcraft, and the little object was called a Cartesian Imp.

BARKER'S MILL.

Experiment 67.—Close one end of a quarter-inch glass tube ten inches long by melting it in the flame of an alcohol lamp. Pass the tube through the centre of a cork,

and place the cork firmly in the smaller end of an argand lamp-chimney. Then fit into this cork four short tubes, bent as shown in Fig. 77. Take a knitting-needle, or a piece of a steel umbrella-frame, sharpen one end, and fasten the other end in a block of wood. Set the chimney and tube down over the piece of wire, so that the closed end of the tube revolves freely on the sharp point of the wire (Fig. 77). Pour water into the chimney, and as it flows out of the end of the smaller tubes notice what occurs.

FIG. 77.

Can you explain why the piece of apparatus turns? Do not say that it is caused by the water pushing out against the air, for the "mill" would revolve without air. Let the outer end of any one of the bent tubes be illustrated by Fig. 78.

Compare the amount of pressure at *Q* with the amount at *P*, due to the head of water in the chimney.

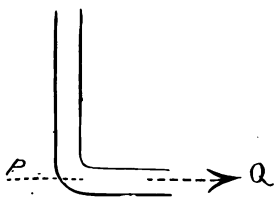


FIG. 78.

This principle was discovered by a man named Barker, and the apparatus has ever since been called *Barker's Mill*. The principle is frequently illustrated in revolving fountains sometimes seen on lawns, and in revolving sprinklers often used for wetting lawns.

SUMMARY.

Hydrostatics treats of liquids.

Liquids exert pressure in every direction. This pressure increases with the depth.

Water in communicating pipes will rise as high as its source.

Water transmits pressure equally in all directions. The pressure upon the side of a vessel containing a liquid is the product of the surface pressed by the depth of water to the middle point of the surface.

Specific Gravity is the weight of a substance compared with the weight of an equal bulk of some other substance taken as standard. For solids and liquids, distilled water is the standard; for gases, hydrogen is the standard.

Questions and Problems.

1. In what directions do liquids at rest exert pressure?

2. State the three conditions upon which the pressure of a liquid upon the bottom of a vessel depends.

3. How much water does a piece of floating wood displace?

4. What is meant by the specific gravity of a substance?

5. Give the weight of a cubic foot of water.

6. Put the palm of the hand over the top of a lamp-chimney, and push the chimney down into water. Why does the water rush up the tube when the hand is removed?

7. Explain why a liquid stands at the same height in the spout as in the body of a tea-pot.

8. If you try to lift out of water a large stone that is on the bottom, it moves easily till it emerges from the water, when it suddenly becomes very heavy. Explain this.

9. Why is it difficult to keep one's feet on the bottom when water is chin-deep?

10. Explain the principle of the hydraulic press.

11. Iron is heavier than water. Why, then, does an iron ship float?

12. A tank filled with water is two feet long, one foot deep, and eighteen inches wide. It has a pipe three feet long, the area of whose cross section is two square inches, leading down from the bottom. What is the pressure upon the end of the pipe when closed?

13. A solid weighs fifteen pounds in air and ten pounds in water. What does an equal volume of water weigh? What is the specific gravity of the solid?

14. Would a piece of iron float in melted copper ?

15. Refer to the specific gravity table, and tell what solids will float on mercury.

16. Does a person float more easily in salt water or in fresh water ?

17. A piece of ore weighed forty grains in air, but lost thirty grains when weighed in water. What was its specific gravity ?

18. Suppose the specific gravity of petroleum is .88, and that a quart of water weighs forty ounces ; find how many gallons of petroleum will weigh thirty-eight and a half pounds.

19. A vessel draws more water in a river than in the ocean. Why ?

20. The double gate of a canal is twenty-five feet wide and ten feet high. When the water is ten feet deep in the canal, what is the pressure on the gate ?

CHAPTER V.

PNEUMATICS.

Experiment 68.—Take a small empty bottle. Is it really empty? If it is not empty, what does it contain? Tie over the top a piece of thin rubber tissue. Place the bottle in a large pickle bottle, as in Fig. 79. Put a rubber stopper in the pickle bottle with a tightly fitting glass tube in one hole. Stop the other hole of the cork. To the glass tube attach a piece of thick rubber tubing. Put the tube to the mouth, and draw out the air. What effect is observed in the small bottle standing on the bottom of the pickle bottle? Is it the air that exerts pressure? If so, why did we not notice the pressure against the rubber before drawing the air out of the larger bottle?

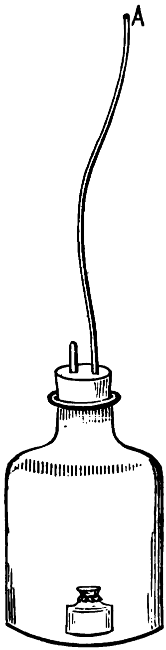


FIG. 79.

Experiment 69.—Take two bottles, as in Fig. 80. Fit the tube tightly in the cork, and put it in the bottle *A*. Let the tube be bent so as to extend nearly to the bottom of both bottles. Before putting in the cork with the tube, fill bottle *A* about

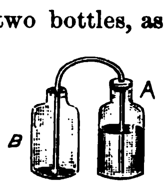


FIG. 80.

half full of water and put just enough in *B* to cover the end of the tube. Place these under the receiver of an air-pump or in the pickle bottle used in Exp. 68, and exhaust the air, observing closely what happens to the water in *A*.

Air exerts an expansive force when the outer pressure is removed.

Experiment 70.—Tie a piece of rubber tissue over the large end of the lamp-chimney. What substance is there on each side of the rubber?

Put a rubber stopper in the other end of the chimney, stop one of the holes, and into the other fit tightly a short piece of glass, to which is attached a piece of rubber tubing (Fig. 81). Draw the air out of the chimney through the tubing, noticing whether the air outside presses the thin rubber down into the chimney. In what direction is the pressure?

Air exerts a pressure downward.

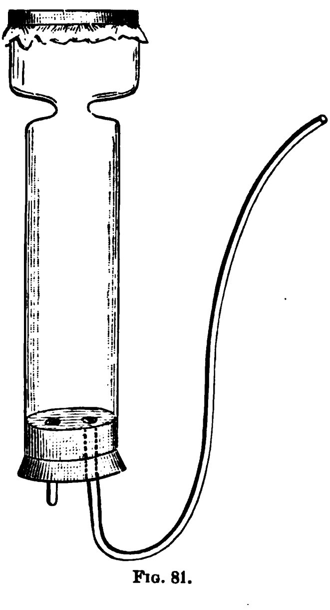


FIG. 81.

Experiment 71, known as Torricelli's Experiment. Take a piece of quarter-inch glass tubing thirty-three inches long. Tie tightly over one end a piece of mem-

brane such as comes tied over the stoppers of perfumery bottles, having previously soaked it in water to make it pliable. Put the tube aside till the membrane dries. Then fill the tube with mercury,* put the finger over the open end, and carefully invert it into a small cup containing a little mercury (Fig. 82). See that no air passes up through the mercury into the top of the tube. Notice that the mercury flows out until it is at a height of about thirty inches. With a pin prick a hole through the membrane, and notice what takes place. Why did not the mercury flow completely out of the tube before the membrane was pricked?

FIG. 82.

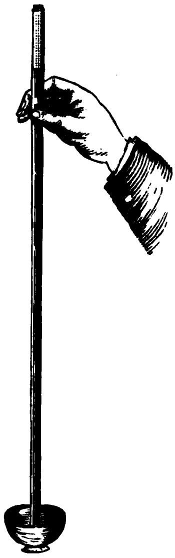


FIG. 83.

Explanation.—In this experiment it is evident that some force equal to the weight of the column of mercury is holding the mercury up in the tube. As air exerts pressure downward, and as air is the only substance in contact with the mercury, it is quite plain that the air presses the mercury up the tube, and that as soon as the air is allowed to

* Twist a piece of paper into the shape of a hollow cone, and use this as a funnel to fill the tube.

enter the top of the tube the mercury falls, because the air pressure is the same at both ends of the tube.

A tube of mercury thirty inches high and one inch square weighs nearly* fifteen pounds, therefore, a column of air one inch square and the height of the atmosphere above the earth at the level of the sea must weigh fifteen pounds to balance the column of mercury.

At the level of the sea, air exerts pressure on a square inch of surface equal to a force of about fifteen pounds.

This pressure we shall sometimes call *one atmosphere.*

If some liquid lighter than mercury were used to perform Exp. 71, would the tube have to be longer or shorter than for mercury?

Mercury is 13.6 times as heavy as water. How long then must a tube be to perform Exp. 71 with water.

If the mercury stands at twenty-eight inches, how long must a tube be to perform Exp. 71 with water?

The Barometer.—A tube of mercury as used in Torricelli's experiment illustrates a common barometer, for if you should allow the tube to remain with the top closed, you would notice from day to day that the height of the mercury varied. Some days the height of the column of mercury would be less than thirty inches, some days more than thirty inches. This shows that the pressure of air is not always the same. When the pressure of air becomes light the column of mercury falls. This fact is explained as follows:

The earth is surrounded by a great ocean of air, concerning the depth of which authorities differ. Some scientists say that the air extends fifty miles above the surface, while

* 14.7 pounds.

others say it extends as high as five hundred miles. Whatever its height may be on an average, it is not always the same height in one place or the same height at all places.

FIG. 84.

The barometer shows exactly all changes of atmospheric pressure. The height of the barometer does not tell the kind of weather, but any sudden rise or fall indicates a change of weather.

The atmosphere becomes less dense as we ascend from the surface of the earth. If a barometer is carried up a mountain the mercury is found constantly to fall as the elevation increases. As a rough rule the barometer falls an inch in ascending nine hundred feet.

Fig. 84 is a sketch of a siphon barometer.

The space above the mercury in the tube of a barometer is free from air, and is called a Vacuum.

THE COMMON PUMP.

Experiment 72.—Take the piece of glass tubing used in performing Torricelli's experiment, place the end in a tumbler of water, and, by applying the mouth to the upper end, draw out the air. Why does the water rise in the tube? If you draw out some of the water, why does more water rise in the tube?

If the tube were thirty-six feet long, and you could exhaust all the air from the tube, how high would the water rise when the barometer stands at thirty inches? See p. 99.

Experiment 73.—Fit up the following piece of appa-

ratus: Take a lamp-chimney and place in the lower end a rubber stopper, closing one hole *A* of the stopper (Fig. 85). Through a small piece of soft leather thrust a wire nail, and drop this into the hole in the rubber stopper to act as a valve (see *D* in the figure). Next select a rubber stopper with two holes, that will slide easily up and down the inside of the chimney. Wind a strip of cloth about this stopper *B*, so that it will work water-tight in the chimney. Into one hole of the stopper put a stick for a handle, and into the other hole *E* put a wire nail thrust through a piece of leather, to act as a valve. A hole may be bored through the chimney at *F* (see Appendix, § 2), and a piece of rubber tubing inserted for a spout.

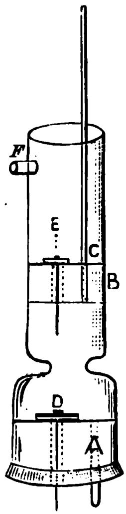


FIG. 85.

Now place the lower end of the chimney in water, with the plunger *B* pushed down as far as convenient.

Raise the plunger nearly to the top of the chimney. What do you push out when you raise the plunger?

What comes up through the valve *D*? What causes it to rush up? Now lower the plunger. Why does the water not run back through *D*? Raise and lower the plunger several times, and explain fully how the pump acts.

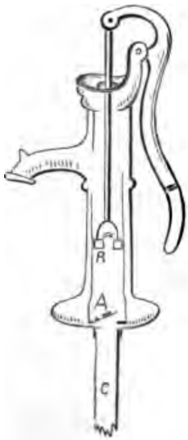


FIG. 86.

Test.—Explain how the common pump

(Fig. 86) works. *A* is the valve in the lower part of the barrel, or cylinder; *B* is the valve in the piston, or plunger. The pipe *C* leads to water.

THE FORCE-PUMP.

Experiment 74.—Take the piece of apparatus you fitted up for Exp. 73, remove the valve *E*, and stop up the hole in the plunger. Take out the piece of glass used to close the hole *A*, and insert in the hole a piece of bent glass tubing, like *G*, Fig. 87. With rubber corks and glass tubing complete the piece of apparatus, as shown in Fig. 87, being careful to have the valve *O* work easily.

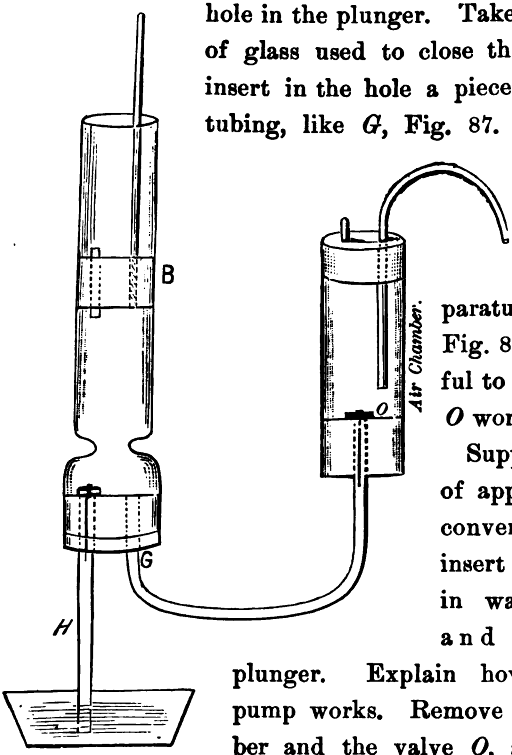


FIG. 87.

Support the piece of apparatus in any convenient way, and insert the tube *H* in water. Raise and lower the plunger. Explain how this force-pump works. Remove the air-chamber and the valve *O*, and work the pump.

Why does a continuous stream of water flow from the pump when the air-chamber is attached?

Test.—Fig. 88 is an illustration of a force-pump, frequently seen. The plunger, instead of being solid as in some kinds of force-pumps, has a valve *A*. The cylinder, however, is air-tight, as the collar *C*, through which the plunger-rod moves, is packed to prevent the water from passing out around the rod. *D* is the valve in the base of the air-chamber; *F* the delivery pipe. *E* is a faucet, used to draw water, but closed when water is to be forced up *F*; *B* is the valve at the base of the cylinder. Explain how the pump works.

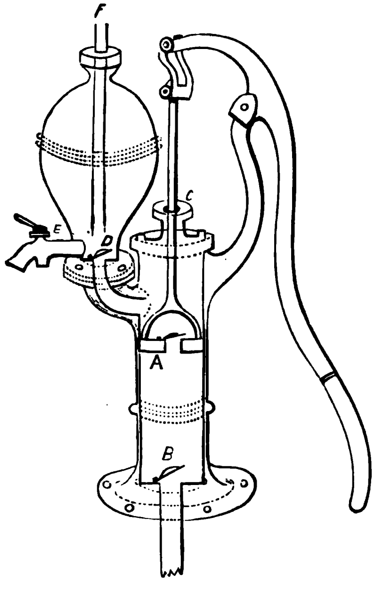


Fig. 88.

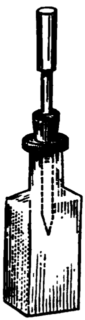


Fig. 89.

Experiment 75.—Draw out a glass tube to a fine point over an alcohol flame (see Appendix, § 2), and push the end through a bored cork and into a bottle, as in Fig. 89. Attach a short piece of rubber tubing to the outer end of the tube. By means of the mouth draw all the air from the bottle possible, pressing the rubber tubing so as to prevent the air from going back into the bottle. Place the end of the rubber tubing under water and remove the pressure. A little

fountain is thus produced. Explain why the fountain flows.

THE SIPHON.

Experiment 76.—Take a small glass tube about eight inches long, and bend it in the shape shown in Fig. 88 (see Appendix, § 2), so that one end may be longer than the other. Fill the tube with water, holding the finger tightly over the short end. Insert the short end in a tumbler of water, letting the long end hang over the tumbler, as in Fig. 91. Notice what takes place. Again fill the tube with water and place the finger over the end as before. This time place the longer end in the tumbler. Which way does the water flow now? Why is it that the water flows up the short end of the tube and down the long end?

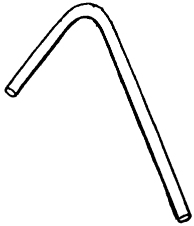


Fig. 90.

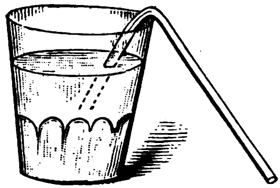


Fig. 91.

Explanation.—The siphon is filled with water, and the shorter arm is immersed, as shown in Fig. 92; or, having placed the shorter arm in the water, the air is exhausted by applying the mouth at the orifice *D*. In the latter way, a vacuum is produced in the siphon, and the water in *A* will rise and fill the tube.

The water will flow as long as the shorter arm dips below the surface of the water in *A*, or until the water stands at the same level in the two vessels *A* and *D*. The continuous flow is caused by the difference in pressure at

A and *D*. At *A* there is a pressure of one atmosphere minus the weight of a column of water equivalent in height to *A B*. At *D* there is a pressure of one atmosphere minus the weight of a column of water equivalent in height to *C D*. Since a column of water *C D* weighs more than a column of water *A B*, and the upward pressures at *A* and *D* are equal, each being one atmosphere, there is less pressure at *D* than at *A*, hence the flow.

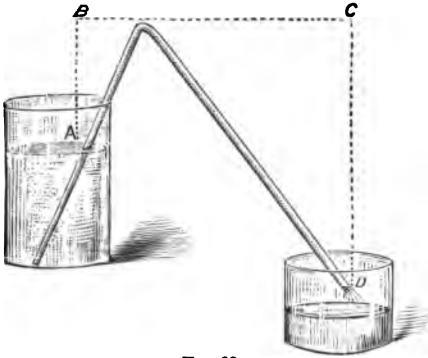


FIG. 92.

The greater the difference between the levels of the liquid in the two vessels, the more rapid will the flow of water be? Why?

Does the size of the tubing of which the siphon is made make any difference in the flow of the liquid? Why?

Is there any limit to the height of the shorter arm? Why?

When the liquid is at the same level in the two vessels, why does the flow stop?

If we exhaust the air from the siphon by placing the mouth at the orifice *D*, what causes the water in the vessel *A* to rise and fill the siphon?

THE AIR-PUMP.

The air-pump (Fig. 93) is a machine used to exhaust air from vessels. It consists of a piston *B* (Fig. 94) working air-tight in a cylinder. In the piston is a valve opening upward. The cylinder is connected by a tube *F*, with a ground glass plate *P* (see larger figure) covered by a bell

jar *A*, called the receiver. The receiver has a ground edge so that when it stands on the plate it will be air-tight.

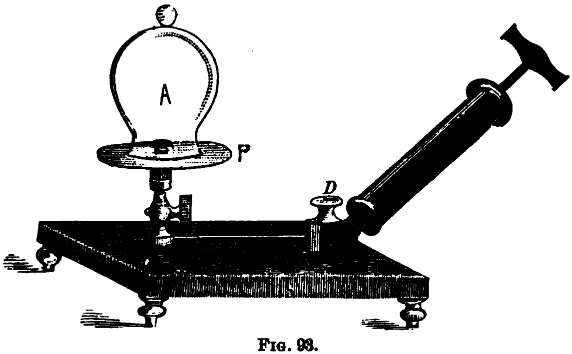


FIG. 93.

D is a screw to admit air under the receiver when necessary.

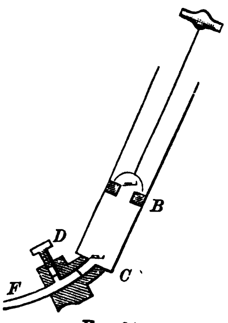


FIG. 94.

As the piston *B* is lowered to the bottom of the cylinder, the valve opens in the piston, and the valve *C* closes (Fig. 94). When the piston is raised to the top of the cylinder, the valve in the piston closes, the air in the cylinder above *B* is pushed out, thus tending to form a vacuum in the cylinder under the piston. But air by its expansive force will spread out through all the space in a vessel confining it, hence the air that was confined in the receiver expands through the tube *F*, lifts the valve *C*, and fills both the receiver and the cylinder. If the capacity of the receiver is as large as the capacity of the cylinder, there is but half the quantity of air in the receiver that was there before the piston was raised. When the piston is lowered again, the valve *C* closes, and as the air in the

cylinder is prevented by C from rushing back into the receiver, it escapes through the valve in the piston B, so long as the piston is moving down. The air can never be entirely exhausted from the receiver, because only a part of the air is taken out at each stroke of the piston. A perfect vacuum cannot, therefore, be produced by an air-pump.

Experiment 77.—Take a large flask having an air-tight stopper to which a piece of rubber tubing is attached, and a clamp to press the tubing together. Weigh these accurately.

Pump the air out of the flask, and close up the tubing with the clamp so that air cannot rush back into the flask. Weigh again. Is there any difference in the two weights?

Suppose you should force air into the flask and stop the flask tight. Would the flask weigh more or less than it did before forcing air into it?

Air has weight.

Experiment 78.—With two glass tubes, one A, ten inches long, and the other B, fifteen inches long, and a piece of rubber tubing C, forty-four inches in length, fit up an apparatus, as in Fig. 95. Secure the rubber tubing to the glass by twisting copper wire tightly about the tubing. Fasten the shorter glass tube A to the window casing or any upright standard.

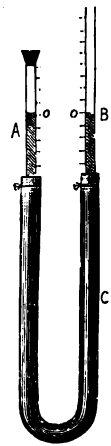


Fig. 95.

Fit a cork in the end of tube A, and measure downward four inches from the bottom of the cork. Calling this point zero, graduate the standard or window casing in inches in

either direction. Now remove the cork and hold the apparatus, as in Fig. 95. Pour in mercury until it stands at zero, and is on a level in both tubes. Replace the cork in the shorter tube, and to secure the cork drive a nail over the top of it into the standard.

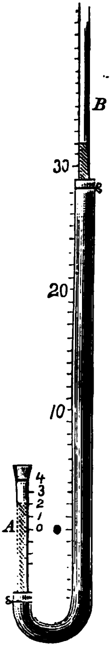


FIG. 96.

How many atmospheres of pressure are there on the mercury in each tube?

Now raise the tube *B*, as in Fig. 96, until the four inches of air in the tube *A* have been compressed into the space of two inches. What is the height of the mercury in the longer tube? How many inches higher is it than the mercury in the shorter tube? How does this difference compare with the reading of the barometer? *

How many atmospheres of pressure are now exerted on the air confined in the shorter tube? Lower the tube *B*, as in Fig. 97, until the air in the tube *A* occupies double the space that it did at first, or eight inches. How much higher does the mercury stand in tube *A* than in tube *B*? What is the ratio between this difference and the reading of the barometer? If, then, the pressure of the air on the surface of the mercury in the

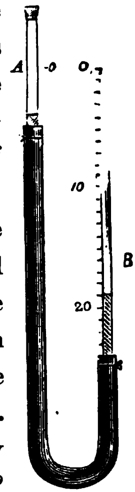


FIG. 97.

* Very few schools possess a barometer. Some member of the school, however, can ascertain the reading of a barometer on the morning that Exp. 78 is to be performed.

open tube *B* sustains a weight of mercury in the closed tube *A* equal to one-half an atmosphere, how many atmospheres of pressure are exerted on the air in the tube *A*?

Raise the tube *B* until the air in the shorter tube is compressed one-fourth, and note the difference between the heights of the mercury in the two tubes. How many atmospheres of pressure are exerted on the air in tube *A*? Lower the tube *B* as before, until the air expands one-fourth. How many atmospheres of pressure are exerted on the air in tube *A*?

Comparing the amount of contraction and expansion of the air in the closed tube with the number of atmospheres of pressure upon it, can you state the law of the compressibility of gases?

The volume of a gas is inversely proportional to the pressure exerted upon it.

This law is called *Boyle's Law*, sometimes *Mariotte's Law*, from the names of the men who discovered it about the same time. The law is true for all gases within certain limits, but under great pressure there are variations from it.

SUMMARY.

Pneumatics treats of gases.

Air expands when the outer pressure is removed.

Air exerts pressure downward.

Air exerts a pressure of about fifteen pounds to the square inch at the sea level.

The barometer is an instrument for measuring atmospheric pressure.

The valves of a common pump should not be more than thirty feet apart.

In the force-pump advantage is taken of the elasticity of the air to produce a steady stream of water.

The siphon acts upon the principle of atmospheric pressure, and the difference in weight between the water in the long arm and that in the short arm.

Only a partial vacuum can be formed with an air-pump. The Torricellian vacuum approaches nearest to a perfect vacuum.

Air has weight.

The volume of a gas is inversely proportional to the pressure exerted upon it.

Questions and Problems.

1. Upon what principle does the common elder pop-gun work ?

2. How can you show that air exerts a pressure downwards ?

3. Two siphons have their bore $\frac{1}{2}$ inch in diameter, and their short arms each 1 foot long ; but the long arm of one is 3 feet in length, and the long arm of the other 18 inches. Will one empty a vessel any quicker than the other ? Give reasons for your answer.

4. If you blow strongly through the glass tube into the bottle (Fig. 98), the water will flow out when the mouth is removed. Explain why.

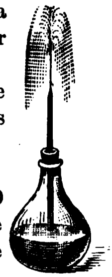


Fig. 98.

5. What is a valve ?

6. When the mercury in a barometer stands at 30 inches, the atmospheric pressure is 14.7 pounds to the square inch. What is the atmospheric pressure when the barometer stands at 27 inches ?

7. A well 20 feet deep is under the floor of a house. Can water be pumped out of the well with a pump set on the ground beside the house, 25 feet from the well ?

8. A barometer which stood at 29 inches at the foot of a mountain is carried to the top, where it stands at 22 inches. How high is the mountain, and what is the atmospheric pressure at the top ?

9. Explain why, when a glass is filled with water and a piece of paper placed over the top, the glass may be inverted (Fig. 99), and the water remain in the glass.

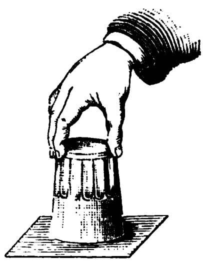


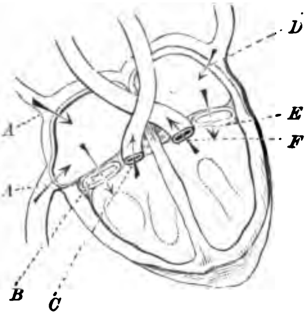
Fig. 99.

10. What is a vacuum ?

11. Explain how water may be raised with a pump out of a well 40 feet deep.

12. The blood enters the right auricle of the heart, as shown in the

diagram, at A, passes through the opening B into the right ventricle, is thence forced through C, through the lungs, and into the left auricle at D, whence it passes into the left ventricle through E, being finally forced into general circulation through F. There is a valve at each opening. Can you show the action of the valves in each auricle, and in each ventricle, when it contracts ?



13. When the barometer stands at 28 inches, how high above the surface of the water can the lower valve of a pump be placed, disregarding friction ?

14. Can you explain why, if you exhaust the air from the chimney (Fig. 81), and turn it in any direction, the rubber tissue over the end of the chimney will be pressed in ?

15. Explain why, when a door is suddenly closed, a remote door to a connecting room often closes quickly.

16. State Boyle's or Mariotte's Law.

17. A quantity of gas occupying a cubic foot of space at a pressure of one atmosphere is compressed by a piston forced down with an additional pressure of one atmosphere. What volume will the gas occupy ?

CHAPTER VI.

HEAT.

HEAT AND TEMPERATURE.

Experiment 79.—Touch the lower part of a stove in which a fire is burning; how does it feel? Touch a stove-lifter after it has been on the stove awhile; how does it feel? Touch a piece of iron in a distant part of the room; does it feel cold or hot? The lower part of the stove feels warm, the top feels hot, and the iron in a distant part of the room is cold.

The agent which produces the sensations of warmth, hotness, and coldness is called Heat.

Experiment 80.—Put on the stove a vessel containing snow or ice, and heat it. When first put on the stove it is ice-cold: after the ice or snow has melted, put the hand in the water and it is still found to be cold; heat it still further and we say it is lukewarm; apply more heat and it becomes warm; still more will make it hot, and then it becomes boiling hot.

We use the terms boiling hot, hot, warm, lukewarm, cold, and ice-cold to express the state or condition the water is in with respect to the heat that affects the hand. These names are the names of temperature; and in these experiments we have used the hand to measure the temperature.

Experiment 81.—Place a piece of hot iron upon a piece of cold iron ; after a while the hot iron loses heat, and we say its temperature falls. What do you notice about the temperature of the piece of cold iron?

What is Temperature?—When a substance is growing colder we say its temperature is falling, and when it is growing warmer we say its temperature is rising.

The state or condition of a body with reference to its heat is called Temperature.

Temperature is not heat itself any more than the level of water in a pond is the water itself ; and as water falls from a higher to a lower level, so heat passes from bodies at a given temperature to bodies at a lower temperature.

Experiment 82.—Take three vessels, the first containing water as hot as the hand can bear ; the second containing lukewarm water, and the third very cold water; plunge the right hand into the first vessel and the left hand into the third, holding them there a short time. Then plunge both hands into the second vessel. How does the water in the second vessel feel to each hand? To which hand does the water feel warm, the hand that was in the first vessel, or the one that was in the third vessel? How can it feel warm to one hand and cold to the other, when we know that both hands are in the same vessel?

Bodily Sensation not to be relied on to determine Temperature.—Exp. 82 proves that we cannot depend upon the hand or bodily sensation to determine temperature. This fact is also noticeable in a room containing several people. Some will feel cold, while others will feel warm.

Instruments are made by which temperature can be accurately measured. Such instruments are called *thermometers.*

GENERAL EFFECT OF HEAT ON SOLIDS, LIQUIDS, AND GASES.

Experiment 83.—Take a piece of iron about twelve inches long, fasten one end to a block of wood with nails, as shown in Fig. 100. Rest the other end upon a fine knitting-needle, placed upon a hard block of wood which should be very smooth. If the block is not smooth, place a smooth piece of metal under the needle. Fasten a broom splint to the end of the needle with sealing-wax and let it hang down over the end of block *B*, Fig. 100. Tack a semi-circular scale *A* on the end of the block. Heat the iron bar by means of an alcohol lamp or some other hot flame, by moving the flame from one end toward the other along the bar. Does the splint move to the right or to the left?

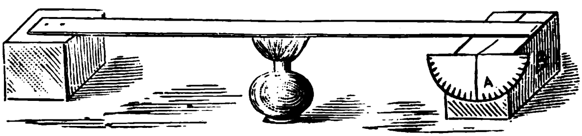


FIG. 100.

What effect, then, does the heat have upon the iron bar? Repeat the experiment, using brass instead of the iron, also copper and glass, and note the effect upon each material that is used.

Expansion in length is called *linear* expansion.

Experiment 84.—Take a piece of round iron three-fourths of an inch in diameter, and file a hole in a piece of

sheet iron or tin, so that the piece of iron will pass through the hole closely. Heat the piece of round iron and attempt to put it in the hole through which it passed before being heated. You will notice that the heat has expanded the iron so much that it will not pass through the opening.

In Exp. 84 the round iron grew larger in area than the area of the hole. This showed what is called *superficial* expansion. When in addition to this superficial expansion we take into account that the bar also expanded in length, there results, as a total, what is called *cubical* expansion.

Experiment 85.—Take a two-ounce flask or thin bottle and fill it with clear water that has been boiled, and allow it to cool. Color the water with red ink. Pass a tube twelve inches long through one of the holes of a rubber cork, close the other hole, and insert the cork and tube in the flask (Fig. 101). Be sure that the flask is so full of water that when the cork is pressed in, the water will rise in the tube a short distance above the cork. Mark on the tube the height to which the water rises, by tying a fine thread around the tube. Immerse the flask in hot water. Notice how the water in the tube moves. Give reasons for the two movements which the column of water makes. After a few minutes remove the flask. Notice the effect upon the water in the tube.

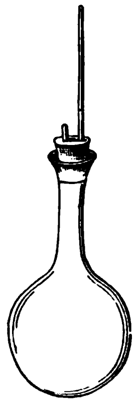


FIG. 101.

Experiment in the same way with alcohol. Do not, however, color the alcohol, and be sure there are no flames

near. If possible, try the experiment with mercury. What effect has heat upon liquids?

Experiment 86.—Take a large flask, having a capacity of one quart. Bend a tube, as shown in Fig. 102, and put in the bend a small quantity of mercury. Hold the bulb of the flask between the two hands. Watch the mercury. What does the experiment teach?

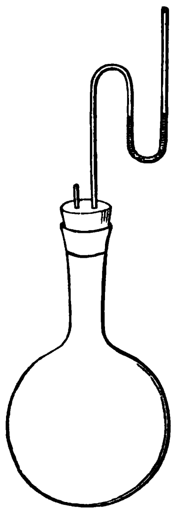


Fig. 102.

The Thermometer.—You noticed in Exp. 85 that water rose in the tube when heated, and when the heat was withdrawn the water slowly fell again; this was true also of the mercury and the alcohol. The fact that liquids expand by means of heat, and contract when heat is taken from them, suggested the method of making the thermometer. Alcohol is more suitable than either water or mercury, because of its greater expansion when heated; but alcohol and water both boil and become vapor at a much lower temperature than mercury, and mercury is therefore used in making most thermometers. Then, too, if the tube is left open, as in Exp. 85, the liquid would evaporate, and the pressure of the atmosphere would also affect the rising of the liquid. Hence the tube must be closed, and there must be no air above the liquid, because the elasticity of the confined air would affect the rising of the liquid upon being heated. Then there is so much liquid in the flask that it takes a long time for it to feel the effect of the heat. By using a small vessel and a tube with a very fine bore the best results can be obtained.

The standard mercurial thermometer of commerce is made as follows : It consists of a glass bulb and a stem with a minute hair-like bore. Through the opening in the end of the tube, the bulb and a portion of the stem are filled with mercury, which is then boiled to expel all the air and moisture. While the mercury is boiling, and has thus reached its greatest expansion, the top of the tube is twisted after being heated by means of a blow-pipe. It is necessary to *twist* the tube when melted to close the opening ; for if it were simply drawn out to a fine thread the opening would still exist. After the open end is closed the mercury is allowed to cool, and as it settles in the tube it leaves a vacuum above it. The thermometer is now ready for a scale. The thermometer is plunged into melting ice or snow, and the point to which the mercury then settles is marked the *freezing point.* It has been proven that the mercury will always fall to this same point when subjected to the same temperature.

The next point to be fixed is the point at which water boils ; but here great care must be taken, for water containing different minerals or other impurities does not always boil at the same temperature. Then, too, the pressure of the atmosphere affects the point or temperature at which water will boil. In order, therefore, to get a standard, pure water is boiled, the barometer standing at a height of thirty inches. The thermometer having been taken from the melting ice is confined in the steam rising from the boiling water, and the height to which the mercury rises is called the *boiling point.*

Different Kinds of Thermometers.—All thermometers are made thus far alike, the point at which the water boils being called the *boiling point* on the thermometer, and the point at which the mercury stopped while the bulb was plunged in melting ice is called the *freezing point.* In the thermometers most in use the distance between these two

points is divided into one hundred and eighty divisions, and thirty-two more divisions of the same length are continued below the freezing point, the thirty-second being marked 0, or zero. The boiling point on this thermometer is one hundred and eighty divisions, or degrees as they are called, above the freezing point, or two hundred and twelve degrees above the zero point. A thermometer graduated thus is called the Fahrenheit thermometer.

There are two other scales in use to mark temperature between the freezing and boiling points (see Fig. 103). Study this figure so that you can draw it from memory. Notice that the mercury is at the same height in each tube. Both of these thermometers make the freezing point zero, but one makes one hundred divisions between the freezing and the boiling points, while the other makes but eighty divisions between the two points. The one having eighty degrees between these two points is called Réaumur's ; the one having one hundred degrees is called a Centigrade thermometer. If these three thermometers, then, with their different scales attached, were plunged into a freezing mixture, in two of them mercury would stand at zero, while in the other it would stand thirty-two degrees above zero ; for you will remember that in the Fahrenheit thermometer the zero point was placed thirty-two degrees below the freezing point. The Fahrenheit thermometer is used mostly in the United States, England, and Holland ;

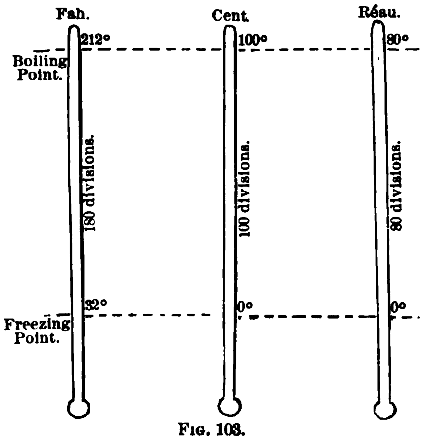


Fig. 103.

the Réaumur is used in Germany, and the Centigrade principally in France. As the parts of the Centigrade scale can be conveniently written as decimals, it is employed almost universally for scientific purposes.

Questions and Problems.

1. The difference between two temperatures is 72° Centigrade. What is the difference in Fahrenheit degrees ?

2. A Fahrenheit thermometer reads 60° ; what would be the reading on a Centigrade thermometer ?

3. Change the following readings Fahrenheit to Centigrade readings: 50°, 12°, – 40°*, 200°, 18°.

4. Change 80°, 15°, 5°, – 18° Centigrade to Fahrenheit readings.

5. Change 120° F. to C. reading ; 80° C. to F.; 64° F. to C.; – 18° C. to F.; 150° F. to C.; – 32° F. to C.; 100° F. to C.

The Selection of a Thermometer.—To select a thermometer, take the one that marks the average temperature of several thermometers which differ only three or four degrees from each other. In a good thermometer the bore must be of uniform size and the tube free from air.

Limits of Temperature a Mercurial Thermometer will Measure.—Thermometers made with mercury can be used for all ordinary purposes, but when mercury reaches – 39.2 degrees F., that is 39.2 degrees below zero, it solidifies. It is therefore of no use in measuring very low temperatures.

To measure temperature in very cold climates, the thermometer tube is filled with alcohol containing some coloring matter. Pure alcohol never freezes in the greatest cold that has been found.

When heat is applied to the mercurial thermometers the mercury will rise until it reaches 660 degrees F., then it boils and passes off in vapor. When it is needful to measure temperatures greater than 660 degrees F., other in-

* The minus sign denotes that the temperature is below zero.

struments are used, based upon the expansion of metals, or the alteration, by change of temperature, of some property of the metals, as electrical conductivity.

An Air Thermometer.—Take two flasks, *A* and *B*, Fig. 104. Fit into each a rubber stopper, and connect the two flasks with a piece of glass tubing eighteen inches long. The stopper in flask *B* should have a second hole opening out to the air. Put water colored with red ink into flask *B*, and let the glass tube dip below the water, as shown in Fig. 104. Warm the flask *A* so as to expel a little air; the colored water rises in the tube.

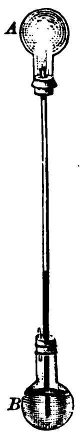


Fig. 104.

The apparatus forms a simple *Air Thermometer*, the movements of the colored water in the tube showing the effect of a change of temperature upon the confined air in flask *A*.

Place the air thermometer and a mercurial one in a cool place, note the point to which the water rises in the tube and the temperature marked by the mercurial thermometer.

Put both thermometers in a warm place. Note the point where the water stands in the tube and the temperature indicated by the mercurial thermometer. Make a scale on paper dividing the distance between the highest and lowest points in the tube into as many divisions as there are degrees between the highest and lowest temperature marked by the mercurial thermometer.

Which is the more sensitive to slight changes of temperature, a mercurial thermometer or an "air thermometer"?

CONVECTION.

Experiment 87.—Take a small beaker half full of water and sprinkle into it some bran or fine sawdust, then

place it over a flame and boil the water. Describe the movement of the bran or sawdust.

In this experiment the water is heated by circulation. That is, the portion of the water that the heat reaches becomes heated and rises through the colder water to the surface, while the cooler portions sink and take their places over the flame, until all portions of the water reach the boiling point.

The process of heating by circulation of molecules is called Convection.

Experiment 88.—Fit up a piece of apparatus as shown in Fig. 105. *A* is an inverted bottle with the bottom cut off (see Appendix, § 2). *B* is an eight-ounce flask. The tube *C* connects the lower part of *A* with the lower part of *B*; the tube *D* connects the upper part of *A* with the upper part of *B*. Fill the whole apparatus with cold water, taking great care that all the bubbles of air are out of flask *B*. Color the water in *A* and apply heat to the flask. Note the result. What does the experiment teach?

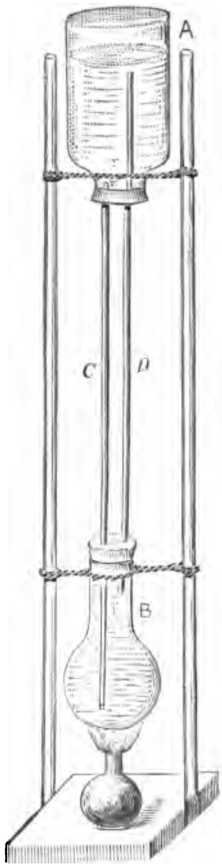


Fig. 105.

Gases are heated by convection in the same manner that liquids are.

CONDUCTION.

Experiment 89.—Heat a piece of iron at one end. Touch the head of a match to the iron and see how far from the source of heat the match can be ignited. Place an iron rod and a copper rod of equal size in the flame of a lamp, and note the point farthest from the flame on each rod that a match can be lighted by simply holding it on the metal. The heat passes along the rod, being communicated from one molecule to another.

The flow of heat through an unequally heated body, from molecule to molecule, is called Conduction.

Experiment 90.—Place a fine piece of muslin on a sheet of lead and drop a burning coal upon it. Note what occurs, and tell what you think is the reason.

Place another piece of muslin upon a block of wood and drop a burning coal upon it. Note what occurs, and explain why.

Is lead a good conductor of heat?

Is wood a good conductor of heat?

Place a few pieces of lead in a paper pill-box. Heat gradually. The lead melts. Place a strip of a business card in the molten lead. It is charred. Why was not the box charred in melting the lead?

Experiment 91.—Take a test-tube, place in the lower end a piece of ice, around which a strip of sheet lead is wound to sink the ice, and nearly fill the tube with water. Place the tube so that the water in the upper portion of the tube is directly over the flame of the lamp. Notice

that the water in the upper part of the tube boils, while the ice remains in the lower part. Or put water in a test-tube and hold in the flame, as shown in Fig. 107. Is the heat applied to the upper portion of the tube conducted by

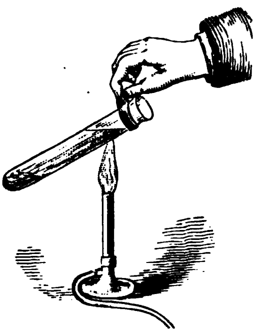


FIG. 106.

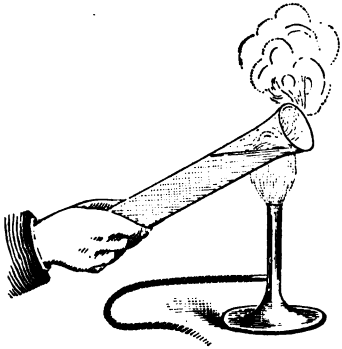


FIG. 107.

the water to the lower portion? Is water a conductor of heat? Other liquids would give the same result that the water does in this experiment.

Are liquids good or poor conductors of heat?

In the following list the metals are given in order of the conducting power, the best conductor being placed first.

1. Silver.	4. Zinc.	7. Lead.
2. Copper.	5. Tin.	8. Platinum.
3. Gold.	6. Iron.	9. Bismuth.

Experiment 92.—Hold a piece of wire gauze over a flame (Fig. 108), and then lower it slowly to the bottom of the flame. Does the flame pass through the gauze? If you have a gas burner, place the gauze half an inch above the

jet (Fig. 109), turn on the gas, and apply a match above the gauze. Does the gas burn below the gauze?

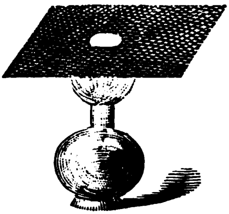


FIG. 108.

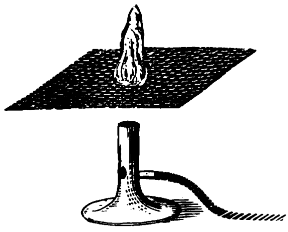


FIG. 109.

Experiment 93.—Wrap a thin piece of writing paper once around a smooth, round piece of copper, brass, or iron, about an inch in diameter, and hold it in the flame. The paper will not be burnt, because the metal inside conducts the heat away so rapidly that the paper does not become hot enough to burn. Can you now explain what was observed in Exp. 92?

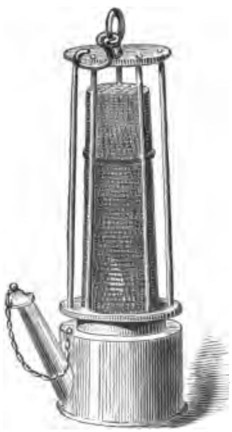


FIG. 110.

The Safety Lamp.—Sir Humphry Davy discovered the fact you observed in Exp. 92, and took advantage of it in making his safety-lamp. The safety-lamp consists of wire gauze enclosing a lamp (Fig. 110), and is used by miners when combustible gases are likely to be encountered in mines.

EVAPORATION.

Experiment 94.—Half fill a tumbler with water, and place over it a clean piece of glass—a piece of broken

window-pane will answer. Let it remain over night, and in the morning examine the glass which covered the tumbler.

What do you see on the piece of glass? How did it get there?

If the piece of glass had not been placed over the tumbler, what would have become of the water which now adheres to the glass?

If the tumbler were allowed to stand uncovered, what would become in time of the water in it?

Set a pail of water out of doors and let it remain a few days.

What becomes of this water?

What do you mean by the statement, "It dries up"?

The quiet formation of vapor at the surface of a liquid is called Evaporation.

Evaporation is one of the most useful processes in the distribution of moisture.

EBULLITION.

Experiment 95.—Fill a beaker half full of water, and place it over a Bunsen burner or the flame of an alcohol lamp.

Watch the water until large bubbles of vapor form rapidly at the bottom and rise to the surface.

Put a thermometer in the water and note the temperature.

Continue the boiling of the water for some time, and notice whether there is any change of temperature pro-

duced when the water is made to boil more rapidly than it boiled at the beginning.

Do you think you can make the water hotter than two hundred and twelve degrees? *

The rapid formation of bubbles of vapor at the bottom of a liquid is called Ebullition, or Boiling.

The boiling point remains constant during ebullition.

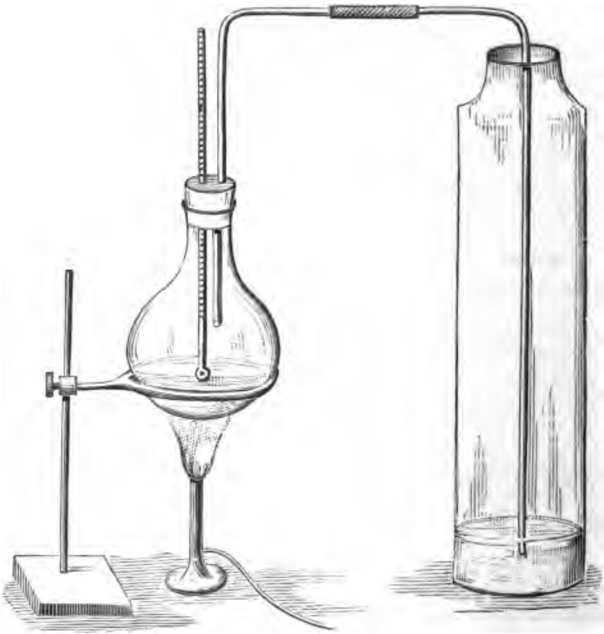


FIG. 111.

Experiment 96.—With a flask, a rubber stopper, a

* Water that boils at two hundred and twelve degrees must be pure, and it must be boiled in the open air.

piece of glass tubing, and a thermometer, fit up a piece of apparatus, as shown in Fig. 111.

Boil the water in the flask with the bottle a third full of water.

At what temperature does the water boil?

When the steam escapes from the end of the tube, fill the

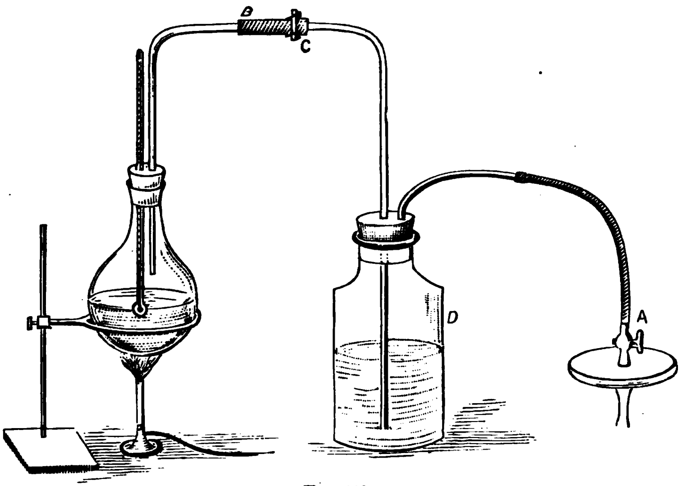


FIG. 112.

bottle nearly full of water, and again notice the temperature at which the water boils in the flask.

What caused the temperature to rise?

Why did it take a higher temperature to keep the water boiling when the bottle was nearly full than it did when there was only a small amount of water in it?

How does pressure affect the boiling point?

An increase of pressure raises the temperature at which a liquid boils.

Experiment 97.—With parts of the same apparatus, shown in Fig. 111, fit up a piece like that shown in Fig. 112.

Be sure that the thermometer and glass tube fit tightly in the rubber cork. Fill the bottle *D* half full of water. Boil the water in the flask and remove the lamp. Note the temperature at which the water boils. When a short time has passed, apply the end of the tube *A* to the air-pump, and exhaust the air from the bottle.

The pressure of the air is thus removed from the surface of the water in the bottle, and this lessens the pressure upon the water in the flask.

Or close the rubber tube at *B*, detach the flask at *C*, and turn it upside down. Pour cold water over the flask to hasten the condensation of the steam.

What effect does the removal of pressure from its surface have upon the water?

What was the temperature shown by the thermometer when the water was boiling, and the space above it was filled with steam?

What was the temperature at which it boiled after the tube had been closed, and the pressure removed by the partial condensation of the steam?

What effect does removing pressure have upon the boiling point of a liquid?

A decrease of pressure lowers the temperature at which a liquid boils.

Have you watched the process of boiling closely enough to tell whether there is any difference between bubbles of air and bubbles of vapor?

Can you tell to what the clicking sound is due which is heard while the water is boiling?

CONDITIONS AFFECTING EVAPORATION.

Experiment 98.—Heat a quart of water nearly to the boiling point, and pour it into a pan about three inches deep.

Notice that vapor rises from the water. Do bubbles of steam or vapor come from the bottom of the pan as in ebullition. From what part of the liquid does evaporation take place?

Pour into a pan three inches deep a quart of cold water. Compare the evaporation from the cold water with that from the hot water by holding a piece of clean, cold glass over each. From which does evaporation take place the more rapidly?

From what you have learned in the foregoing experiments, answer these questions:

What effect has temperature on evaporation?

What effect has extent of surface on evaporation?

What effect has the removal of the pressure of the atmosphere on evaporation?

DISTILLATION.

Experiment 99.—Fit up such a piece of apparatus as is shown in Fig. 113. See that the lamp-chimney is full of water. Keep the vessel *A* constantly filled with cold water, and let the water run from the rubber tube *B* into a pail. Place in the flask a mixture of salt and water, and boil it for at least a quarter of an hour. Taste the water that has collected in the tumbler.

Why does the water in the lamp-chimney become warm?

The process of changing a liquid into vapor by means of heat, and then condensing the vapor by cold, is Distillation.

The Use of Distillation.—Distillation is frequently used in the arts to separate liquids from solids. Water may be

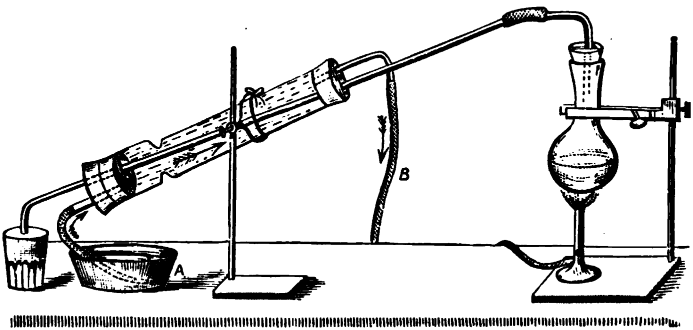


FIG. 113.

purified by this means, as water in evaporating is freed from its impurities.

LATENT HEAT.

Experiment 100.—Take two beakers or tumblers of the same size. Fill one beaker two-thirds full of small pieces of ice, and put into the other an equal weight of ice-water. Put a thermometer in each, and note the temperature. Then place both beakers in a pan of boiling water that you have just removed from the flame. Stir constantly the ice in one of the beakers.

Let the beakers stand in the hot water till the ice has

all melted, and then quickly note the temperature of each.

As both beakers are of the same size, and have stood in the hot water the same length of time, each must have received the same amount of heat.

In which one does the temperature remain the same?

As both were at the same temperature when placed in the water, and both have received the same amount of heat, what has become of the heat which was absorbed by the beaker in which the temperature did not rise?

In what state was the matter in this beaker before it was put into the hot water? In what state was the matter after it had been subjected to heat, though the temperature was not raised?

The heat which changes a body from a solid to a liquid, or from a liquid to a gas, without change of temperature, is called Latent Heat. The heat which is expended in raising the temperature of a body is called Sensible Heat.

SPECIFIC HEAT.

Experiment 101.—Put a pound of mercury into a vessel, and a pound of water into another vessel of the same size and the same material.

Place each over the same source of heat. When the water has risen five degrees, note the temperature to which the mercury has risen.

If the experiment is carefully made, the temperature of the water will be to that of the mercury as one to thirty.

Ascertain how long the water must be kept over the source of heat to raise its temperature as high as the tem-

perature of the mercury rose while that of the water was rising five degrees. You will find that it takes about thirty times as long to raise water to a given temperature as it does mercury.

Next, take half a pound of sheet lead, roll it up so as to form a hollow cylinder, and suspend it by a string in boiling water for five minutes. At the end of that time the lead has the same temperature as the boiling water. Now quickly immerse the lead in a half pound of water at thirty-two degrees F. Find the temperature of the water when it ceases to rise.

The lead falls in temperature much faster than the water rises in temperature.

Heat the half pound of water to boiling, remove it from the flame, and immerse the roll of sheet lead in it. When the lead has remained in the water five minutes, remove it and ascertain as accurately as possible its temperature. Note the temperature of the water when the lead is removed.

We see that equal weights of different substances receiving the same amount of heat have their temperatures raised unequally. This is expressed in other words by saying that all substances do not have the same *specific heat.*

The amount of heat required to warm a given weight of any substance one degree compared with the amount of heat required to warm an equal weight of water one degree is called the Specific Heat of that substance.

For comparison, a standard of specific heat is necessary; water is taken as the standard, its specific heat being 1.

SPECIFIC HEAT OF A FEW SUBSTANCES.

SUBSTANCE.	SPECIFIC HEAT.
Hydrogen	3.4090
Water	1.0000
Ice	.4890
Air	.2375
Iron	.1138
Copper	.0952
Silver	.0570
Tin	.0562
Mercury	.0333
Lead	.0314

ARTIFICIAL COLD.

Experiment 102.—Tie some cotton wool upon the bulb of a mercurial thermometer and wet the wool with ether. Why does the temperature fall ?

Tie a piece of cotton cloth over the bulb of the air thermometer. Wet the cloth with alcohol. Explain the result.

Experiment 103.—Cut out a round piece of sheet copper an inch and a half in diameter. Form it into a little capsule or basin by hammering it upon some concave surface. Pour a few drops of water upon the table, set the little basin in the water, and partly fill the basin with carbon disulphide. With a pair of bellows blow over the surface of the carbon disulphide till it is evaporated. Ice is formed under the capsule. Repeat the experiment, but instead of placing the little basin upon the wooden table, place it upon a piece of sheet copper. Why are you unable to form ice as in the first part of the experiment ?

Experiment 104.—Crush a quantity of ice. Take a bottle holding four or five ounces ; fill it to the top with

water. Push into the nozzle a rubber cork with a thermometer through one hole and a piece of glass tubing about twenty inches long through the other. The water will rise five or six inches in the tube. See that there is no air in the bottle. Put this piece of apparatus in a wooden pail or a small box and pack around it snow or ice. Do not cover the neck of the bottle with ice. A little salt may be mixed with the ice. Tie a fine thread around the tube to show the height of the water in the tube. Follow the movement of the water in the tube by tying another piece of thread about the tube and moving it down as the water falls. When the water has fallen to the lowest point, let the thread remain, and note the temperature marked by the thermometer. As the water is cooled by the freezing mixture, does it occupy less or more space ? in other words, does it become rarer or denser? At what temperature does it reach its greatest density? When the water began to freeze, did it occupy more or less space than it did when put into the freezing mixture?

Water reaches its maximum density at 39.2 degrees F.

Water freezes at 32 degrees F., and expands* when freezing.

RADIATION.

Experiment 105.—Heat an iron or a brick very hot. Hold one hand a little distance from the brick, and with

* Like water, cast iron, bismuth, and antimony expand when solidifying, and can therefore be used for casting, as they will take up the impressions of the moulds in which they are allowed to solidify. Gold, silver, and copper contract, and hence coins must be stamped with a die.

a small piece of cardboard, fan the air between the brick and the hand held in front of it. Your hand feels the heat, but the heat is not communicated to your hand by the air.

Go near a hot stove and remove the lid. The heat seems to strike out into your face at once.

The heat which is thus thrown across space is called *radiated* heat.

Move your hand from one position to another around the hot brick; over it; under it; to the right; to the left; in every direction.

Is the heat radiated in every direction?

Hold the hand at various distances from the brick. Does the distance from the heated body affect the amount of heat which the hand receives?

The heat received from a hot body at a distance of two feet is one-quarter of what it is at a distance of one foot; at a distance of three feet it is one-ninth; at a distance of four feet it is one-sixteenth; at a distance of five feet it is one twenty-fifth, etc.

Heat is radiated in every direction, and decreases in intensity as the square of the distance increases.

Experiment 106.—Procure two tin fruit-cans—one which has just been opened, and the other very rusty. Polish the tin of the new one as bright as possible. Heat two quarts of water to boiling, and pour it into the two quart fruit-cans.

Hold the hand at equal distances from each. Which radiates the greater amount of heat?

Rough surfaces radiate well; smooth surfaces are poor radiators.

In which can will the water retain its heat the longer—the bright can or the rusty one? Why?

Which stove will "throw out" the more heat, one that is highly polished or one that is rusty?

ABSORPTION.

Experiment 107.—At short but equal distances from a heated brick or a two-quart pail of boiling water, set up a piece of bright tin and a piece of sheet iron or tin painted black. Let them remain for a short time. Which feels warmer, the bright, smooth substance, or the dark, rough substance? Which do you conclude is the better absorbent of heat, a bright, smooth body, or a dark, rough one?

REFLECTION.

Experiment 108.—Heat a brick or a large piece of iron

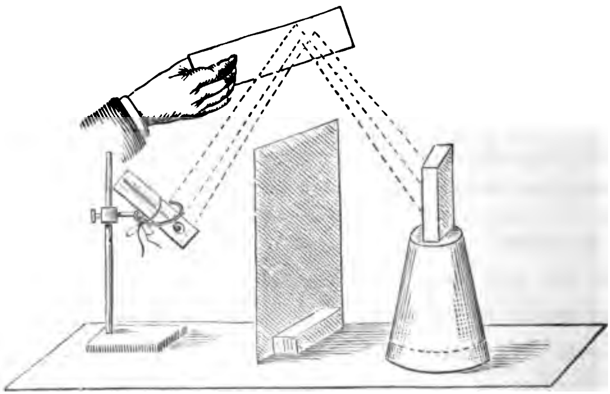


FIG. 114.

very hot. Set it upon some body so that it will not burn

the table. Place in front of the brick a pasteboard screen, as in Fig. 114. Upon the opposite side of the screen suspend a thermometer. Hold a bright piece of tin above the screen at different angles until a position is found in which the other hand placed over the thermometer feels the heat. Remove the hand from over the thermometer, and keep the tin in the same position. See whether the temperature marked by the thermometer rises. The heat was not radiated in an unbroken straight line from the brick to the thermometer, but was reflected to the thermometer by the bright tin surface. The rays of heat which pass from the hot body to the reflector are called *incident* rays; those which pass from the reflector to the hand or thermometer are called *reflected* rays.

The Steam-Engine.—The steam-engine is a machine in which the expansive force of steam is the motive power. The expansive force or tension of steam formed when the temperature of water is two hundred and twelve degrees F. is equal to one atmosphere, or fifteen pounds, to the square inch. When the pressure upon boiling water is increased, its boiling point is raised and the expansive force of steam is increased. As the expansive force of steam is due to heat, the steam engine is a machine by means of which heat is transformed into work. The essential parts of a steam-engine are the boiler, in which steam is generated, and the cylinder, in which the expansive force of the steam acting alternately on a piston moves it to and fro.

Experiment 109.—Cut off a piece of lamp-chimney (*A*, Fig. 115) three and a half inches long (see Appendix, § 2).

Into each end of it fit a cork, with a quarter-inch hole near the edge. In the centre of one cork bore a second hole *M*, about one-eighth of an inch in diameter, so as to allow the stick *B* to move easily back and forth. On the end of the stick *B* fasten a disk of cardboard *C*, that will move easily back and forth in the glass cylinder. Then take a block of wood *D*, two and a half inches long, seven-eighths of an inch wide, and five-eighths of an inch thick, and chisel out smoothly a hole in this block, one and three-fourths of an inch long, five-eighths of an inch wide, and half an inch deep.

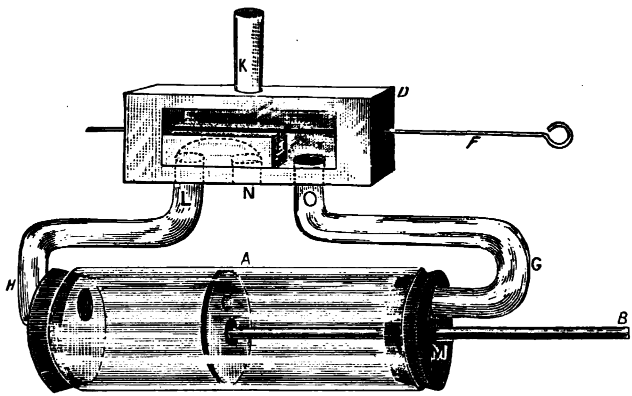


FIG. 115.

In one side of the little box thus made bore three quarter-inch holes, *L*, *N*, and *O*, one-fourth of an inch from each other and the same distance from the inside ends of the box. In the middle of the opposite side of the box bore one such hole *K*.

Cut out a piece of cork (*E*, Figs. 115 and 116) one and

one-fourth inches long, a scant half inch thick, and three-eighths of an inch high. In the bottom of this small piece of cork cut out a hole, as indicated by the dotted lines (Fig. 116). Put this piece of cork in the box, as shown at *E*, Fig. 115, and pass through the ends of the box and close to the top of the cork a small iron wire *F*. Fasten the iron wire to the cork with shellac. Over the front of the box glue a piece of glass, making it air-tight.

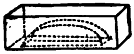


FIG. 116.

Next bend two pieces of quarter-inch glass tubing *G* and *H*, as in Fig. 115, and insert them into the end holes *L* and *O* in the lower side of the box, and into the holes in the corks, making them air-tight with shellac or sealing-wax. The straight parts of the tube *G* should be a little longer than those of the tube *H*, so that the apparatus may be easily put together. Fit into the upper hole *K* in the box a straight piece of glass tubing, and attach to this a piece of rubber tubing.

We have now a piece of apparatus to show how steam is made to pass into and out of the cylinder of an engine, driving the piston back and forth. *A* represents the cylinder, *C* the piston, *B* the piston-rod, *D* the steam-chest, *E* the slide-valve, *K* the pipe leading to the boiler, and the hole *N* in the steam-chest represents the escape-pipe.

Blow into the rubber tube attached to *K*, moving the wire *F* in and out, and notice the motion of the piston. The disk *C* must move easily and the rod *B* fit easily in the hole *M*, in order that the breath may move the piston. Why is the hole *N* necessary? Of what use is the hole cut in the lower side of the slide-valve *E*?

In the real engine a fly-wheel attached to *B* by a crank gives the machinery a steady motion. The rod *F* is made to move out and in at the proper times by an eccentric attached to the shaft of the fly-wheel.

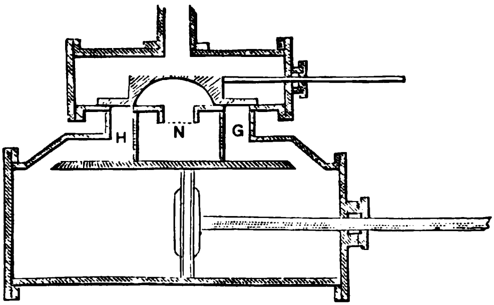


FIG. 117.

Fig. 117 represents a cross-section of the cylinder and steam-chest of an engine. In the figure the slide is in such a position that the piston is at rest.

Make a drawing similar to Fig. 117 to represent the position of the slide-valve when the piston-rod is moving out.

Make another drawing to represent the position of the slide-valve when the piston-rod is moving in.

The corresponding parts of Fig. 115 and Fig. 117 are lettered alike.

SOME SOURCES OF HEAT.

Experiment 110.—Place upon a large piece of iron a piece of copper or lead or iron, and hammer it. Notice that its temperature is raised. In this instance the rise in temperature is due to *percussion*.

Experiment 111.—Rub vigorously together two pieces of wood; or bore a hole in a hard piece of wood with a brace and bit. Notice that the temperature of the bit and also that the temperature of the surfaces of the two pieces of wood is raised. In this case the rise in temperature is due to *friction*.

Experiment 112.—With a pair of hand-bellows blow upon the bulb of a thermometer for a few minutes. Notice that the temperature of the mercury rises. Air on being heated expands (Exp. 110), and when it is compressed, as it is with the bellows, it gives out heat.

The rise of temperature observed in performing Experiments 110, 111, and 112 resulted from the conversion of *mechanical energy* into heat.

SUMMARY.

Heat is that agent which produces the sensations of warmth or coldness.

Temperature is the state or condition of a body with reference to its heat.

The thermometer is an instrument for measuring temperature.

Heating bodies causes them to expand; cooling bodies causes them to contract. (For exceptions to this, see p. 134.)

The freezing point is the temperature at which pure water freezes—32° F., 0° C., 0° R.

The boiling point is the temperature at which pure water boils when the barometer stands at thirty inches—212° F., 100° C., 80° R.

Convection is the process of heating by the circulation of molecules.

Conduction is that process of heating in which the heat is diffused through a body from molecule to molecule.

Fluids (liquids and gases) are heated by convection. Solids are heated by conduction.

Combustible matter will not burn until heated to the proper temperature.

Evaporation is the quiet formation of vapor at the surface of a liquid.

Ebullition, or boiling, is the rapid formation of vapor within the body of a liquid.

The boiling point of a liquid is raised in temperature (1) by an increase of pressure, (2) by the presence of foreign matter in solution.

Evaporation is affected by the amount of heat, by the extent of surface, and by the pressure of the atmosphere.

Distillation is the process of changing a liquid into vapor by means of heat and then condensing the vapor by cold.

Latent heat is the amount of heat which is expended in changing the condition of a body without changing its temperature.

Sensible heat is the heat expended in raising the temperature of a body.

The specific heat of a substance is the amount of heat required to warm it one degree compared with the amount required to warm an equal weight of water one degree.

Artificial cold may be produced by evaporation.

Water reaches its maximum density at 39.2° F.

Radiation is the passage of heat from the source of heat through space.

Heat is radiated in every direction, and decreases in intensity as the square of the distance increases.

Rough surfaces are good radiators. Smooth surfaces are poor radiators.

Rays of heat are reflected by smooth surfaces.

Mechanical energy can be transformed into heat.

Questions and Problems.

1. What is heat ?
2. What is cold ?
3. Has ice any heat ?
4. What is temperature ?
5. Distinguish between heat and temperature.
6. What is a thermometer ?
7. Distinguish between a thermometer and a barometer.

8. Change $-40°$ C. to Fahrenheit reading, and $-40°$ F. to Centigrade reading.

9. $-36°$ F. equals what reading on the Centigrade thermometer ?

10. 20° F. equals what reading on the Centigrade thermometer ?

11. 20° C. equals what reading Fahrenheit ?

12. Why should the bore of a thermometer be uniform throughout ?

13. Can you pass heat from a colder to a hotter body ?

14. If we heat an object, how will it affect its size ?

15. Can you mention an exception to the answer to the foregoing question ?

16. Why is the temperature of the body not a safe standard by which to determine the amount of heat an object contains ?

17. In Exp. 82, page 113, why did the same vessel of water feel both hot and cold ?

18. What kind of a thermometer would you employ to measure high temperatures ? Why ?

19. To measure low temperatures ? Why ?

20. To measure extremely low temperatures ? Why ?

21. Why do coach-wheels become set when the axles are not sufficiently greased ?

22. The spaces between the ends of the rails of a railroad are greater in winter than in summer. Why ?

23. Why do blacksmiths heat wagon-tires before putting them on wheels ?

24. What are the fixed points on a mercurial thermometer, and how are they determined ?

25. Why do glasses crack when suddenly heated ?

26. Explain why vessels and pipes in which water is confined burst when the water is frozen.

27. Show that water is a bad conductor.

28. Why does a soap-bubble ascend when first blown ?

29. Why does it descend after a time ?

30. Explain the process of ventilation.

31. What causes the fire to burn better on a cold day than on a warm day ?

32. What do you mean when you say that the fire draws well, or has a good draught ?

33. Why does vapor ascend ?

34. Why do chimneys sometimes smoke when the fire is first lighted ?

35. Why is it that on a cold morning iron feels colder than wood, both having been exposed to the same degree of cold ?

36. Do good conductors feel warmer or colder to the touch than poor conductors of the same temperature ? Why ?

37. Why is ice preserved from melting by being wrapped in flannel ?

38. Does the carpet feel warmer than the marble hearth ? Why ?

39. If they were both warmer than the body, what sensation would they produce ?

40. Why do cotton or linen sheets feel cool, while woollen blankets feel warm ?

41. Why does the mercury in the thermometer, though sealed up, indicate external temperature ?

42. Explain why the glass covering of conservatories, or hot-beds, renders the confined air warmer than the atmosphere outside.

43. Why are double windows often put up in the winter ?

44. Why does snow keep the earth warm ?

45. Why cannot the warmth of the earth escape through the snow ?

46. Why do ponds become dried up in dry, hot weather ?

47. Why are bright tin pans not so good to bake bread in as dark ones ?

48. Mention three circumstances which will affect the rapidity of evaporation.

49. Will water boil at a lower temperature on the top of a mountain, or at the sea level ? Why ?

50. Mention three circumstances which will affect the temperature at which a liquid will boil.

51. What is boiling ?

52. What causes the clicking sound heard when water boils ?

53. Why does boiling water bubble ?

54. Upon what fact or principle of physics does distillation depend?

55. Can latent heat be changed into sensible heat ?

56. Why does fanning one's self produce a sensation of coldness ?

57. When a pitcher of ice-water is brought into a warm room, why is it soon covered with moisture ?

58. Why is salt mixed with ice in freezing ice cream ?

59. If a tumbler is held near the mouth of a boiling kettle, why is it soon covered with moisture ?

60. Why is the window-pane covered with moisture if we breathe against it ?

61. What is meant by the maximum density of water ? At what temperature does water reach its maximum density ?

62. Why does ice float ?

63. Why does water when frozen occupy more space than when it is in the liquid form ?

64. How may heat be diffused ?

65. How is the earth's surface heated ?

66. How is the atmosphere heated ?

67. Is a good absorbent a good reflector ?

68. Is a good conductor a good radiator ?

69. We learned in Exp. 95 that the boiling point is constant during ebullition. After the water becomes 212°, what becomes of the heat that does not raise the temperature of the water ?

70. Distinguish between boiling and evaporation.

71. The temperature of a closed room is 85°. Water is sprinkled on the floor, and the temperature of the room falls several degrees. Explain why.

72. A pond of water at sundown has a temperature of 45°. The weather grows very cold during the night, and before morning the pond is frozen over. Was there any circulation of the water produced by the cold ? When did the circulation stop ?

CHAPTER VII.

SOUND.

Experiment 113.—Stretch a cord tightly, as shown in

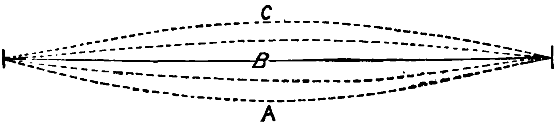


FIG. 118.

Fig. 118. Now pull it aside suddenly. A sound is produced.

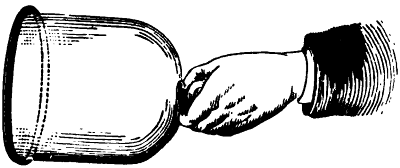


FIG. 119.

Place a small glass bead in a bell-jar, hold the jar in one hand (Fig. 119), and strike the edge with the knuckle or a piece of wood. A sound comes from the bell-jar, and the bead is heard tapping the glass. The edge of the bell-jar is in motion.

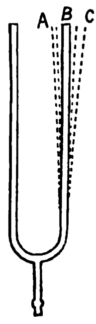


FIG. 120.

Strike a tuning-fork, and hold a piece of paper so that it will touch the side of the fork near the end of the prong. A quick succession of slight taps is heard.

Grasp at the middle a piece of quarter-inch glass tubing about thirty inches long. With a piece of damp cloth

grasp the tubing near the hand holding it, and draw the cloth quickly up and away from the tubing (Fig. 121). A sound is heard.

The movements, back and forth, of the cord, of the bell-jar, of the tuning-fork, and of the glass tubing are called *vibrations.*

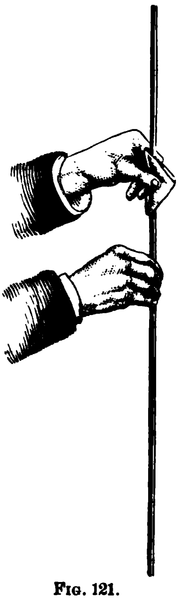


FIG. 121.

Sound is produced by the rapid vibrations of a body. A body which produces a sound is called a Sonorous body.

Terms.—A *complete* vibration is the movement from *A* to *C*, and back again to *A* (Figs. 118, 120, and 122). The distance from *A* to *C*, or from *C* to *A*, is the *amplitude* of the vibration.

The vibrations of the cord, of the bell-jar, of the tuning-fork are from side to side, or at right angles to the length of the body, and are called *transverse* vibrations. The vibration of the glass tubing is in the direction of its length. Such vibrations are called *longitudinal.*

FIG. 122.

Experiment 114.—Pull the cord aside lightly, then strongly. In what respect do the vibrations differ?

Hold the glass tubing at the middle, and set the tube vibrating by drawing the damp cloth along the tube. Begin to draw the cloth at one-third of the distance towards the end, and set the tube vibrating. In what respect do the vibrations differ?

SOUND NOT PROPAGATED IN A VACUUM.

Experiment 115.—Fit a flask with a rubber cork, having two holes. Pass a piece of wood through one hole, and attach to the end of the wood a toy-bell or a small sleigh-bell (Fig. 123). Stop the other hole of the cork, insert it in the flask, shake, and notice the sound. Remove the cork, put a little water into the flask, and replace the cork, leaving one hole open. Dry the outside of the flask. Heat the flask slowly at first, and then hold it steadily in the flame until the water boils briskly and the steam issues rapidly. Stop the hole in the cork, and remove the flask instantly from the flame. As the flask cools, a vacuum is formed in it.

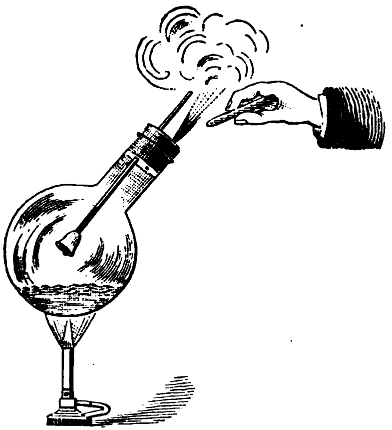


FIG. 123.

Shake the flask, and compare the sound heard with that when the flask was full of air.

Sound is not propagated in a vacuum.

Experiment 116.—Dry the flask, and fill it with illuminating gas by holding the flask over a jet. Replace the rubber cork and shake the bell.

How does the sound compare with that made when the flask was filled with air?

Fill the flask with carbonic acid gas if you have any means for generating it. Replace the cork and shake the bell. How does the sound compare with that made when the flask was filled with air?

The loudness of sound depends upon the density of the gas in which the sound originates, not upon the density of the gas or air which surrounds the person hearing the sound.

Velocity of Sound in Air.—Every student must have made observations like the following: The flash of a gun is seen and then the report is heard. Steam is seen issuing from a whistle and afterward the sound is heard. The axe of a woodcutter falls, and as he is raising it again the sound of the blow is heard. The velocity of sound in air is, therefore, less than the velocity of light.

Sound travels through air at the temperature of freezing, 1,090 feet in a second. At ordinary temperature (sixty degrees F.) the velocity of sound is 1,120 feet in a second.

Velocity of Sound in Water and in Solids.—In water sound travels about four times as fast as in air, or 4,708 feet per second. Let one student place his ear against a telegraph pole, while another strikes the next post with a stone. Two sounds will be heard; the first conducted by the wood and wire, the second conducted by the air.

Was the first or the second sound the more distinct?

Experiment 117.—Obtain a strip of wood eight or ten feet long and about half an inch thick; place a watch upon the end of this strip, and see whether its ticking can be heard at the other end.

Or place a watch on one end of a table or bench, and see whether its ticking can be heard when the ear is placed at the other end.

Does the air or a solid convey sound with the greater intensity?

Sounds travel quicker in solids than in air or water.

Waves.—If we watch a flag when the wind is blowing, we see waves running along the flag from the part near the staff to the end.

Shake a breadth of carpet, and waves pass from the edge in the hands to the outer edge. Neither the flag nor the carpet moves forward, though the waves do. The form of the wave, therefore, travels from one end to the other, moving parts of the flag or carpet up and down, but not lengthwise. In water waves, also, the form only moves forward, while the particles of water simply rise and fall, or have a motion transversely to the direction of the wave.

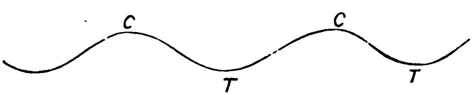


FIG. 124.

The top of the wave is called the crest *C*, the hollow is called the trough *T* (Fig. 124). A *wave length* is the distance from crest to crest, *C* to *C*, or from trough to trough, *T* to *T* (Fig. 125).

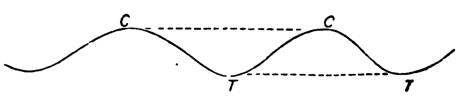


FIG. 125.

Experiment 118.—Procure a piece of brass or steel wire wound in the form of a spiral. Fasten both ends firmly to two fixed pieces of board. Then press four or five turns of the spiral next to one board closely together. Remove the hand quickly, and the spiral vibrates in the direction of its length, or longitudinally. If you notice closely, you will see that there is a movement of the crowded part of the spiral forward and then back again. This is followed by the stretched part. The spiral does not move as a whole; it is only the movement lengthwise and back of the compressed part, followed by the stretched part.

We may regard the compressed part as a *condensation*, and the stretched part as a *rarefaction*.

It is the elasticity of the spiral that allows the condensation and the rarefaction to move from end to end. Were the wire not elastic, the condensation would not pass along the spiral.

When a tuning-fork is set vibrating, the prong moves out and compresses the particles of air next to it *A* (Fig. 126). The particles of air are elastic, and when crowded together tend to expand. In expanding they crowd together the particles of air just beyond, and in this way the compression, or condensation, is propagated.

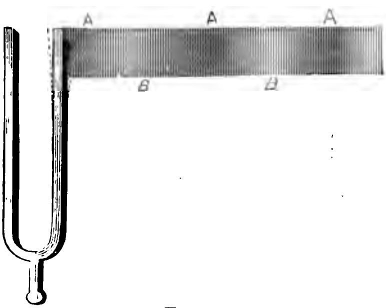


FIG. 126.

When the prong moves back, it causes the particles of air to separate, producing a rarefaction. This rarefaction is propagated

in the same way. The particles of air are vibrating longitudinally, or in the direction the wave is moving.

A sound wave is composed of a condensation *A*, and a rarefaction *B* (Fig. 126). A wave length consists of a condensation and a rarefaction.

When a fire-cracker is lighted and tossed into the air to explode, the report is heard by those on the ground, by those across the street, by those who may be near the upper-story windows, and by those up and down the street. The explosion produced but one sound wave, and as the sound was heard in every direction from the spot where the explosion occurred, the sound wave must have moved out in the form of a constantly enlarging sphere.

When a sonorous body is set vibrating, as, for instance, a bell, there is a series of sound waves travelling out from the bell in constantly enlarging spheres.

Sound travels in all directions from a sounding body.

REFLECTION OF SOUND.

Experiment 119.—Take a large concave reflector, such as is used behind wall lamps, and support it as shown in

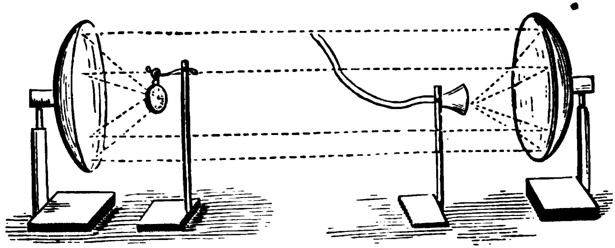


FIG. 127.

Fig. 127. In the focus of the reflector hang a watch. Place another reflector four or five feet from the first one,

and hold in the focus of the second reflector a small funnel with a rubber tube attached. Place the extremity of the tube in the ear, and the ticking of the watch can be distinctly heard. Remove the reflectors, and compare the sound heard with that heard before the removal of the reflectors.

The focus of a reflector can be found approximately by letting the sunlight fall upon it, and measuring the distance to the reflector from the point in front of it, where a piece of dark paper will be set on fire. The point where the paper burns is the focus.

When sound waves are reflected, they follow the same law that waves of light do. (See p. 180.)

In speaking-tubes the sound waves are reflected from the inside of the tube, and cannot spread. The waves are therefore transmitted to long distances with very little loss in the intensity of the sound.

Echoes.—Echoes are caused by the reflection of sound from some surface, as the walls of a building, the sides of a mountain, the trees and foliage of a wood.

The time that elapses between producing a sound and hearing its echo is the time it takes for the sound to go from the sounding body to the reflecting surface and back to the ear.

It is difficult to distinguish more than ten syllables a second—that is, there must be one-tenth of a second between hearing one syllable and hearing the next.

Keeping this fact in mind, and also the fact that at ordinary temperatures sound travels about eleven hundred feet per second, we can easily determine how far away a reflecting surface must be in order to hear a distinct echo.

For sounds to be one-tenth of a second apart, the sound waves must follow each other at a distance of a hundred and ten feet (1,100 feet ÷ 10 = 110 feet). But as the sound wave travels to the reflecting surface and back again, the reflecting surface cannot be nearer than fifty-five feet (110 feet ÷ 2 = 55 feet).

INTENSITY OF SOUND.

Experiment 120.—Construct a piece of apparatus like that shown in Fig. 128 (see Appendix, § 4). It is a crude form of an instrument called the *siren*.

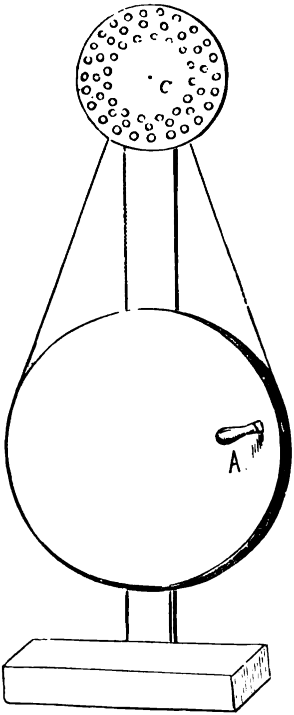


Fig. 128.

Insert a short piece of quarter-inch glass tubing in a piece of rubber tubing. Hold the end of the glass tubing opposite the outer row of holes in the siren. Turn the siren steadily and blow through the rubber tubing. A tone is produced. As each hole in the siren comes opposite the end of the tubing a puff of breath passes through. These puffs of breath produce on the opposite side of the siren a series of condensations. Each of these is followed by a rarefaction, owing to the elasticity of the particles of air. Although the siren itself does not vibrate, it produces sound waves the same as a vibrating body.

Experiment 121.—Turn the pulley-wheel of the siren steadily, so that the cardboard disk shall make, as nearly as possible, the same number of revolutions in each second, and blow lightly through the glass tube at any row of holes. Notice the sound. Now, while the disk is revolving at the same rate, blow as hard as possible.* Notice the sound. How does the first sound differ from the second?

When you blew hard through the disk, a greater condensation and rarefaction was produced than when you blew lightly. The amplitude, therefore, of the vibrating particles was greater when blowing hard than when blowing lightly.

Loudness or intensity of sound depends upon the amplitude of the vibrations.

Experiment 122.—Stretch a string or wire between two supports. Pull the string lightly. Notice the sound. Pull the string with considerable force. Notice the sound. To what was the difference between the two sounds due?

The farther the ear is from a body which is giving forth sound, the fainter is the sound.

If a person who has been standing a short distance from a sounding body moves twice as far away, the sound is only one-fourth as loud. If he moves three times the distance, the sound is only one-ninth as loud. If four times the distance, it is one-sixteenth as loud.

Suppose a person to stand within two feet of a sounding

* Blow-pipe bellows attached to the tubing will give a light and a heavy stream of air more evenly.

body, and then to move twelve feet away from the body; how does the loudness at twelve feet compare with that at a distance of two feet?

The intensity of sound decreases inversely as the square of the distance from the sonorous body.*

MUSICAL SOUNDS.

Pitch.—In the study of sound thus far no distinction has been made between sounds that are musical and sounds that are mere noise.

If we strike a ruler upon the desk, the sound is a noise. The ear hears but one sound wave. If we strike the desk several times in succession, a number of sound waves strike the ear, but there is an interval between, and the ear distinguishes the sounds as so many separate noises. When, however, the sound waves follow one another with perfect regularity, and so rapidly that the ear cannot distinguish the intervals, but one continuous sound pleasing to the ear is produced, we have a *musical* sound or tone.

Experiment 123.—Turn the pulley-wheel of the siren and blow through the outer row of holes. Blow steadily and turn the wheel faster and faster. You notice that the sound becomes higher the faster you turn. Remembering that every puff of air that passes through a hole in the disk produces beyond the disk a condensation, which is followed by a rarefaction, you will see that the faster the wheel turns the greater is the number of sound waves or vibrations produced.

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* The intensity of sound also depends upon the density of the medium in which the sound originates. See p. 149.

The pitch of a sound depends upon the number of vibrations in a given time. The greater the number of vibrations the higher the tone.

Experiment 124.—Stretch a wire or catgut string tightly upon a sonometer* (Fig. 129) (see Appendix, § 4). Near the bridge *A* place another bridge, and move it toward

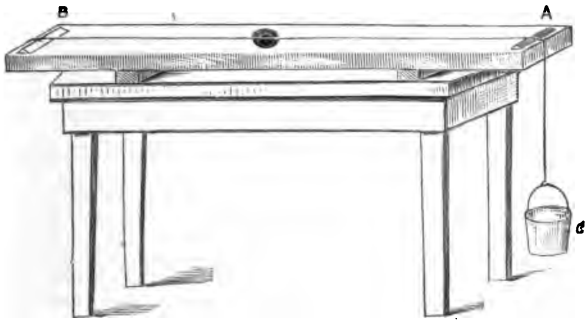

FIG. 129.

B, stopping every two or three inches of distance and sounding the string.

Is the pitch of each note the same? How does the number of vibrations the shortened string makes compare with the number it made before being shortened by the movable bridge?

Experiment 125.—Take away the movable bridge, and attach a tin pail, *C*, to the string (Fig. 129). Put into the pail a weight of three or four pounds. Sound the string, noticing the tone. Put twice as much weight

* Fair results can be obtained by stretching the wire tightly lengthwise of a table or board, with the bridges arranged as stated above.

into the pail, and again sound the string. Put in three times as much weight as at first and sound the string.

What effect does increasing the tension have upon the pitch?

How does the number of vibrations made by the string when last sounded compare with the number it made when it had less tension upon it?

Experiment 126.—Stretch upon the sonometer two strings of the same material and of such size that the diameter of one is about twice that of the other. Fasten to the end of each string the same amount of weight, so that the tension of each will be the same. Sound first one string and then the other. Which gives forth the higher note? Which string, then, makes the greater number of vibrations, the one having the larger or the one with the smaller diameter?

The pitch of a vibrating string depends upon the length, the tension, and the size of the string.

Experiment 127.—Pull a string on the sonometer. Produce a sound of the same pitch upon a piano or an organ, and also upon a flute or other wind instrument. The three sounds differ in what is termed *quality.*

Upon what does the loudness of sounds depend? Upon what does pitch depend? Upon what does the *quality* of sounds depend?

THE MUSICAL SCALE.

Experiment 128.—Turn the siren steadily, and with the [illegible]w through the inner row of holes. Then blow

successively through the second, third, and fourth row. Repeat this several times to gain a correct idea of the notes produced.

Calling the first note *Do*, we recognize the other notes as *Mi*, *Sol*, *Do*, of the musical scale.

Turn the siren more rapidly. The pitch of the four notes is raised, but relative to each other, they are *Do*, *Mi*, *Sol*, *Do*.

Count the number of holes in each row. The numbers stand:

48	60	72	96

or in the ratio of

4	5	6	8

If we turn the siren so that it revolves two and three-quarter times a second, we have for *Do:*

Do..............................	132 vibrations per second.		
Mi..............................	165	"	"
Sol..............................	198	"	"
Do..............................	264	"	"

The *musical scale* consists of seven notes:

Names,	Do	Re	Mi	Fa	Sol	La	Si	Do
Letters,	C	D	E	F	G	A	B	C
No. of Vibrations,	132	$148\frac{1}{2}$	165	176	198	220	$247\frac{1}{2}$	264
Ratios,	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

The note having two hundred and sixty-four vibrations is called the "*middle C*," and the *interval*, or difference in pitch, between that and the *C* below, is called an *octave*. The middle *C* is the first note of a second octave.

Write out the number of vibrations each note of this second octave has, and place the number under its proper letter.

The interval from C to D, D to E, etc., is called a *second*.
" " " C to E, D to F, " " a *third*.
" " " C to G, A to E, " " a *fifth*.

Between all consecutive notes, except E and F, and B and C, another note is inserted. This note is named from the note below, as C *sharp* (C♯), D *sharp* (D♯); or from the note above, as B *flat* (B♭), A *flat* (A♭).

Experiment 129.—Fasten the bell-jar in any way similar to that shown in Fig. 130. Set the edge vibrating by drawing a violin bow across it in one spot, or by tapping the edge with the finger. Hold near the vibrating edge a bead, a spherical piece of cork, or a bit of sealing-wax suspended by a thread. Ascertain by trials the four points where the bead is thrown off farthest by the vibrating edge. Hold the bead midway between these points, and it will be thrown off very little, if any.

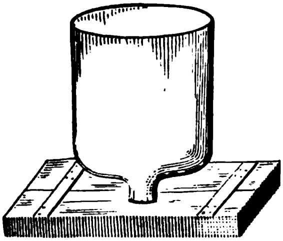

FIG. 130.

The parts which have the least motion in a vibrating body are called the *nodes*. The circle in Figs. 131 and 132 represents the edge of the bell-jar, and the points *N*, *N*, *N*, *N*, the *nodes*. The segments *A*, *A*, *B*, *B*, show the parts of the bell-jar that move in and out during vibration.

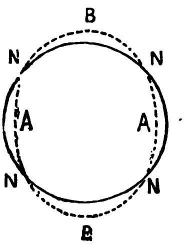

FIG. 131.

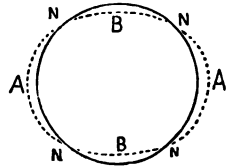

FIG. 132.

Fill the bell-jar partly full of water, bow the edge, and notice the agitation of the water at the nodes and the middle points of the segments.

CHLADNI'S FIGURES.

Experiment 130.—Cut out a piece of window-glass

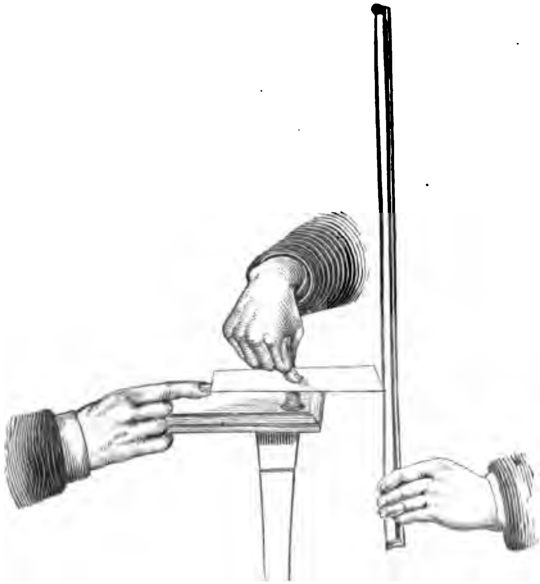

FIG. 133.

seven inches square. Find the middle point, and mark this with ink, or paste a small piece of paper there. Place the middle point over the hole of a spool. Sprinkle fine sand or emery evenly on the glass, and hold the glass firmly upon the spool with the ball of the thumb (Fig. 133). Let another student touch the edge at *N* (Fig. 134), while

you set the glass into vibration by drawing a violin-bow across the edge at *V*. The sand collects on the nodes.

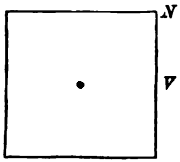

FIG. 134.

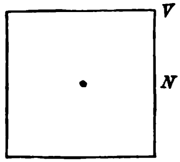

FIG. 135.

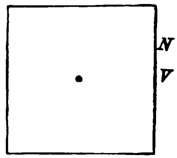

FIG. 136.

Repeat the experiment, touching at *N* and bowing at *V*, as shown in Figs. 135 and 136.

Make drawings to show where the sand collected when the plate was bowed.

See whether you can produce any different figures by touching and bowing at other points than those indicated in Figs. 134, 135, and 136.

The figures formed by sand on vibrating plates are called *Chladni's Figures*, after their discoverer, a famous musician.

Experiment 131.—Sprinkle lycopodium* upon the plate, touch and bow, as in the previous experiment. The lycopodium does not collect on the nodes, but on the parts of the segments where there is the greatest vibration. Can you explain this ?

OVERTONES, OR HARMONICS.

Experiment 132.—*First Part.* Stretch tightly a piece of cord or wire eight to ten feet long. Pull the wire aside and let it vibrate. Notice the tone.

* Do not bring lycopodium near a flame.

The wire can be seen moving from side to side, as shown in Fig. 137.

The vibrating part $A\ C\ B$, or $A\ D\ B$, is called a *ventral segment.*

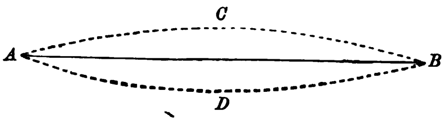

FIG. 137.

The lowest tone that can be obtained from a string without changing its length or tension is called the Fundamental Tone of the string.

Experiment 133.—*Second Part.* Pull the string near the end, or, what is better, draw a violin bow across it, and hold a feather or camel's-hair pencil lightly against the middle point of the string. Remove the feather or pencil just after the bow is withdrawn. Repeat this a few times, and determine whether the string vibrates in one ventral segment or in more than one.

Make a drawing to show the segments you observe, and write the word *node* where you have observed a node.

Again touch the string one-third of the distance from the end, and bow near the end.

How many ventral segments do you notice?

Make a drawing to show these segments, and write the word *node* wherever you have observed one.

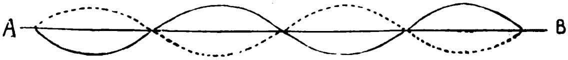

FIG. 138.

Fig. 138 represents a string $A\ B$ vibrating in four ventral segments.

Experiment 134.—Cut out three or four rings* of light paper, as shown in Fig. 139, and slip these on the wire. Place these rings at equal distances apart, damp the wire with the pencil or feather in the middle, and bow strongly. To what places do the rings move?

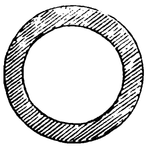

FIG. 139.

Again place the rings at equal distances, damp the wire one-third of the distance from the end, and bow strongly.

To what places do the rings move?

Damp the wire at one-fourth the distance from the end.

Make a drawing to show what you observe with reference to segments and nodes.

Experiment 135.—Sound the wire again. Notice the fundamental tone. Damp the wire at its middle point; sound it. On placing the ear near the wire the octave is heard. Experienced ears can detect the octave while the fundamental tone is sounding.

The octave heard with the fundamental tone is called the *first overtone*, or *harmonic*. Damp the wire one-third of the distance from the end, and sound it. The tone heard with the fundamental is the second overtone, the twelfth higher than the fundamental.

The higher tones heard when a sounding body vibrates in two, three, or more ventral segments are called Overtones, or Harmonics. The combination of

* Instead of rings, several *riders*, or little strips of paper one inch long and one-quarter of an inch wide, doubled thus ∧, may be put on. Find by trial the places where the riders will not be thrown off.

overtones with the fundamental tone gives the quality of sound in any instrument.

REINFORCEMENT OF SOUND.

Experiment 136.—Stop the large end of a lamp-chimney, and pour in water till it rises above the narrow part of the chimney. Set a tuning-fork vibrating, hold it over the top of the chimney (Fig. 140), and pour in water. Stop pouring the water the moment the sound is louder. Measure the distance between the fork and the water. This strengthening of the sound is called *reinforcement* or *resonance.*

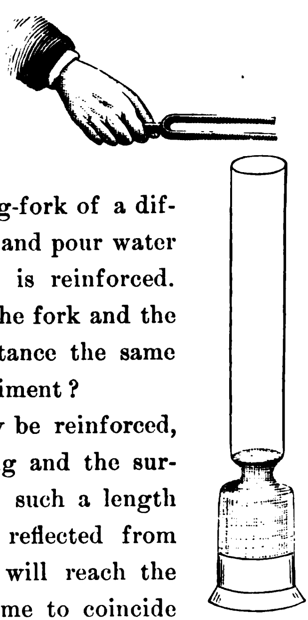

Fig. 140.

Empty the chimney down to the neck.

Procure, if possible, a tuning-fork of a different pitch. Set it vibrating, and pour water into the chimney till its sound is reinforced. Measure the distance between the fork and the top of the water. Is the distance the same as in the first part of the experiment?

In order that the sound may be reinforced, the distance between the prong and the surface of the water must be of such a length that, when a condensation is reflected from the surface of the water, it will reach the prong of the tuning-fork in time to coincide with a condensation as the prong moves upward, thus making a greater condensation in the air outside the tube.

Experiment 137.—Sound a tuning-fork, and note how long the sound is heard. Sound it again, taking care not to strike it harder or bow it stronger than before, and put the handle down upon the table or desk. Do you notice any difference in intensity of sound? Is the sound heard for a longer or shorter time than in the first instance?

Place a cigar-box, with the cover nailed or glued on, upon two tightly stretched strings. Sprinkle a little fine sand on the top of the box. Sound the tuning-fork, and put the handle down upon the box. What is the effect upon the sand?

The tones given out by stringed instruments, like the violin, guitar, piano, etc., are reinforced by the *sounding-board* of each instrument.

INTERFERENCE OF SOUND.

Experiment 138.—Sound a tuning-fork, and hold it near the ear. Revolve it slowly between the thumb and fore-finger. Do you notice any positions where the sound is not heard?

Hold a vibrating tuning-fork horizontally over its resonance tube (Exp. 136), and gradually revolve it. Note the four positions in which there is scarcely any sound heard. These positions are when the side faces of the tuning-fork make an angle of about forty-five degrees with the resonance tube.

When the tuning-fork is in one of these positions, slip over one of the prongs a paper tube (Fig. 141). The sound of the other prong is heard.

We have seen, in Exp. 136, that when a condensation of one sound wave unites with the condensation of another wave a reinforcement of sound ensues. In this experiment a condensation unites with a rarefaction, and the sound is nearly, if not quite, extinguished.

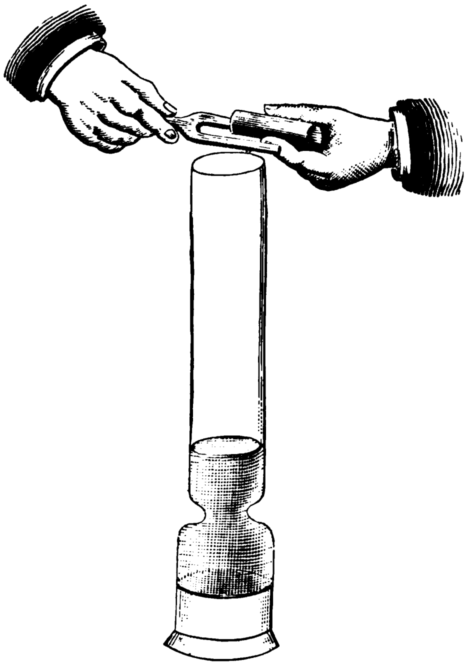

FIG. 141.

The meeting of two series of sound waves, so that the condensations of one series coincide with the rarefactions of the other series, is called Interference of Sound.

SUMMARY.

Sound is produced by the rapid vibrations of a body.

A sonorous body is a body that produces sound.

Transverse vibrations are those in which the vibrating body moves at right angles to the direction of the wave.

In transverse vibrations a wave length is the distance from crest to crest, or from hollow to hollow.

Longitudinal vibrations are those in which the vibrating body moves parallel to the direction of the wave.

In longitudinal vibrations a wave length consists of one condensation and one rarefaction.

Sound is not propagated in a vacuum.

At 32° F. sound travels 1,090 feet per second. At 60° F. sound travels 1,120 feet per second.

In water sound travels about four times as fast as in air, or 4,708 feet per second.

In solids sound travels faster than in liquids and gases.

Sound waves are composed of an alternate condensation and rarefaction of the propagating medium.

A sound wave has the form of a constantly enlarging sphere.

Sound travels in all directions from a sounding body.

An echo is a reflected sound, heard after being reflected.

Laws of Intensity of Sound.—I. The intensity of sound varies directly with the density of the propagating medium.

II. The intensity of sound varies directly as the square of the amplitude of vibration.

III. The intensity of sound decreases inversely as the square of the distance from the sonorous body.

A musical tone is produced by a succession of vibrations that follow one another with perfect regularity and so rapidly that one continuous sound, pleasing to the ear, is heard.

The pitch of a tone is its degree of highness or lowness, and depends upon the number of vibrations in a given time.

The greater the number of vibrations, the higher will be the pitch.

The musical scale consists of seven tones, which vibrate in the ratio,

$$1 : \tfrac{9}{8} : \tfrac{5}{4} : \tfrac{4}{3} : \tfrac{3}{2} : \tfrac{5}{3} : \tfrac{15}{8} : 2.$$

The nodes of a vibrating body are the parts that have the least motion.

The ventral segments are the vibrating parts between the nodes.

Chladni's figures show the nodes and ventral segments of vibrating plates.

The fundamental tone of a vibrating body is the lowest tone that can be produced by that body without change of length or tension.

Overtones, or harmonics, are the tones higher than the fundamental, heard when a sounding body vibrates in two or more ventral segments.

The quality of sound in any instrument is produced by the combination of overtones with the fundamental.

Reinforcement, or resonance, is a strengthening of sound caused by the meeting of two series of sound waves in such a way that the condensations of the one series coincide with the condensations of the other series, and the rarefactions of the one with the rarefactions of the other.

Interference of sound is the meeting of two series of sound waves in such a way that the condensations of the one series coincide with the rarefactions of the other series.

Questions and Problems.

1. Define the terms vibration and amplitude.

2. Explain the difference between a transverse and a longitudinal vibration.

3. In what direction do the particles in a water wave move? In what direction do the particles of air move in a sound wave?

4. Explain what is meant by a wave length.

5. What is the velocity of sound per second at the temperature of freezing?

6. A stone is thrown into a pond. One can count the crests of 16 waves between the shore and where the stone fell, a distance of 27 feet. What is the average length of each water wave?

7. If the velocity of sound on a mild day is 1,120 feet per second, and a sounding body makes 560 vibrations per second, what is the wave length?

8. Four seconds elapse from seeing a flash of lightning to hearing the thunder. How far away was the lightning?

9. How can you show that when a bell is sounding it is vibrating?

10. The prong of a tuning-fork makes 512 vibrations per second. When the velocity of sound is 1,120 feet per second, find the length of each sound wave.

11. What is the form of a sound wave?

12. How does the velocity of sound in air compare with its velocity in liquids and solids?

13. Two strings are of the same length and have the same tension, but one string is larger in diameter than the other. If they are sounded, in what respect will the sounds produced differ?

14. Two strings are of the same size, and are subjected to the same tension, but one string is longer than the other. If sounded, in what respect will their sounds differ?

15. Two strings are of the same length and the same size, but one is subjected to more tension than the other. When set vibrating, will there be any difference in sound? What difference?

16. Explain how the condensation and the rarefaction of a sound wave are produced.

17. Explain why one on the water can hear sounds farther and plainer when the weather is foggy.

18. Explain the meaning of intensity of sound; the meaning of pitch.

19. Upon what does the intensity of a sound depend?

20. Upon what does the pitch of a sound depend?

21. What is an echo?

22. An echo is heard from a ledge of rocks in 20 seconds. How far distant is the reflecting surface of the rocks?

23. A person is a quarter of a mile from the whistle of a factory. How does the intensity of the sound he hears compare with the intensity of the sound heard by a person two miles away? State the law of decrease in intensity.

24. Show how you can illustrate the difference in intensity and pitch of sound by drawing the thumb-nail over the ridged cover of a book.

25. Distinguish between a noise and a musical sound.

26. A certain note has 126 vibrations per second. How many vibrations has its octave?

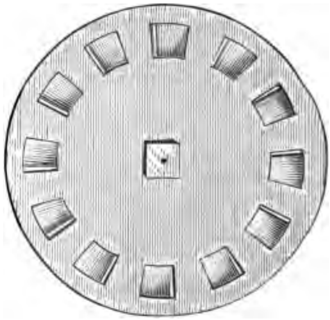

FIG. 142.

27. What is meant by the terms *a second, a third, a fifth,* as intervals in the musical scale?

28. How many vibrations per second has the "Middle C"? When sound travels 1,120 feet per second, find the wave length.

29. What is meant by a node?

30. What is meant by the ventral segment of a vibrating string? Make a drawing to illustrate.

31. What is meant by a fundamental tone?

32. What are overtones, or harmonics?

33. What is resonance? What is interference of sound?

34. Does a vibrating tuning-fork show nodes? How would you find by experiment whether it has nodes, and where they are lo-

cated? Illustrate by a drawing, the facts learned by your experiment.

35. Construct out of cardboard a disk 3 inches in diameter, as shown in Fig. 142. Put a pin through the centre of the disk, so that it may revolve. Make a hollow cone by twisting around the finger a piece of writing-paper. Fasten the edges with mucilage. Now blow into the large end of the cone, and direct the breath, issuing from the small end, upon the small squares of cardboard that are bent back at small angles from the face of the disk. Why does the pitch of the note rise as you blow?

CHAPTER VIII.

LIGHT.

Luminous, Transparent, Translucent, and Opaque Bodies.—Bodies which emit light, as the sun, a lighted candle, the fire, etc., are called *luminous bodies.*

From observation, we know that light passes through air, glass, water, mica, and many other substances. Any substance through which light passes is called a *medium.* (Plural, *media.*)

Substances through which objects may be distinctly seen are called *transparent.*

Name four common, transparent substances.

Substances through which light passes, but through which objects cannot be distinctly seen, are *translucent;* as thin paper, parchment.

Name three other translucent substances.

Substances through which light does not pass are *opaque;* as iron, stone.

Light itself Invisible.—We cannot see light; it is itself invisible, but falling upon objects that are not luminous it makes them visible.

Every point in a luminous body sends out rays of light in every direction.

Experiment 139.—Place a candle, as shown in Fig. 143, and set up three cards, through each of which a pin-hole has been made; a ray of light from the candle will pass

through the three pin-holes only when they are in a straight line.

Admit a ray of sunlight into a darkened room, and dis-

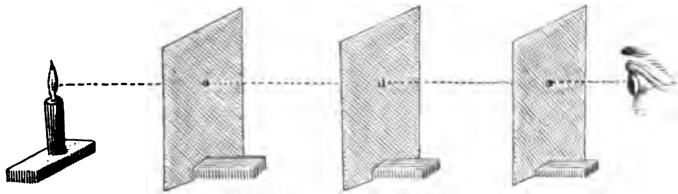

FIG. 143.

tribute a little crayon dust through the air. The path of the ray, as shown by the illuminated dust, is perfectly straight.

Light travels in straight lines.

How Rays of Light are represented.—In diagrams rays of light are represented by straight lines.

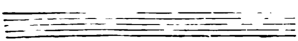

FIG. 144.

One line represents a *single ray*. Several parallel lines represent a *beam* of light (Fig. 144).

FIG. 145.

FIG. 146.

Several lines diverging from a point *A*, or converging towards a point *B*, represent a *pencil* of light (Figs. 145, 146).

SHADOWS.

Experiment 140.—Take any opaque cylinder three or four inches in diameter, and put it on the table in a dark

room. Place two lighted candles four inches away from the cylinder, making the distance between the candles equal to the diameter of the cylinder (see Fig. 147). Notice the shadows—one dark, the others light. Is there any part of the space behind the cylinder that does not receive light from either candle? Can you explain why there are one dark and two light shadows?

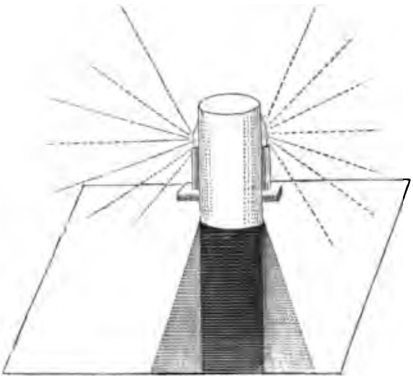

Fig. 147.

Experiment 141.—Fit up a piece of apparatus as follows (Fig. 148): Take the top of a pasteboard box about a foot square. Cut out a piece eleven inches square so as to leave a frame. Paste smoothly on the frame and over this hole a piece of thin white paper. This screen can be set up by placing the side of the box-cover down, and

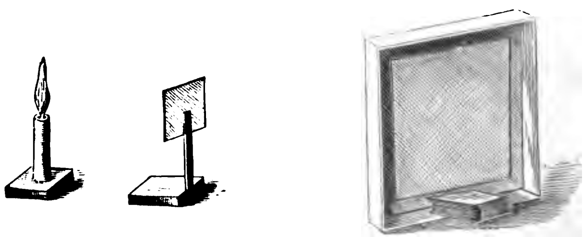

Fig. 148.

putting any convenient weight on the inside. Next, cut out of pasteboard a square, two inches on a side, and mount it as shown in the figure. In a dark room set up the screen, place the square four inches from the screen, and put a lighted candle one inch from the square. You will notice that a part of the shadow on the screen is light, and the larger part dark. Trace carefully with a pencil the outline of the lighter and the darker shadow. The darker shadow is called the *umbra*, the lighter shadow the *penumbra*. Now prick pin-holes through the umbra, and see if any part of the candle can be seen. Next prick pin-holes through the penumbra, above, below, and on both sides of the umbra, and note what parts of the flame can be seen.

Can you explain how the umbra and the penumbra are produced?

THE INTENSITY OF LIGHT.

Experiment 142.—Take a lighted candle and a card two inches square, such as was used in Exp. 141. Fasten to the wall a large sheet of paper for a screen. Place the card eight inches from the screen, and the candle eight inches in front of the card. See that the card is parallel to the screen, and that the middle point of the candle flame is on a level with the middle point of the card. Mark on the screen the outline of the shadow. Measure its sides. You will find that the shadow is four inches on a side. How many square inches does it contain?

If the card is removed, the light that fell upon the card will fall upon sixteen square inches of the screen. Divide

the outline of the shadow on the screen into four square parts. Each part is the size of the cardboard. If the card should be placed sixteen inches from the candle, or twice as far as at first, how much light would it receive compared with the amount it received when eight inches from the candle?

Next, place the card eight inches from the screen, and the candle four inches from the card. Mark on the screen the outline of the shadow. You find that it is six inches square. How many square inches of screen does the shadow cover? Divide the space covered by the shadow into nine squares the size of the card.

If the card is placed twelve inches from the candle, or

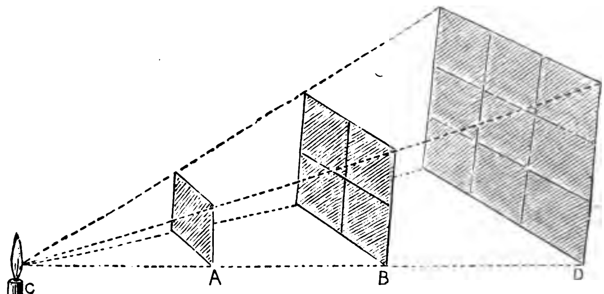

FIG. 149.

three times as far as at first, how much light would it receive compared with the amount it received when four inches from the candle?

Again, place the card twelve inches from the screen, and the candle four inches from the card. Mark the outline of the shadow. You find it to be eight inches square. How many square inches does the shadow cover?

Divide the space into sixteen squares the size of the card. If the card should be placed sixteen inches from the candle, or four times as far as at first, how much of the light it received at first will it then receive?

Study Fig. 149.

The light falling upon a given area varies inversely as the square of the distance from the source of light.

Experiment 143.—Hold near the eye a card with a pin-hole in it. Look through the hole at a pencil three or four inches long, placed at such a distance that its ends may just be seen. Move the pencil farther and farther away, noting that its dimensions apparently diminish as it recedes.

Let *A* (Fig. 150) represent the hole in the card, and *B*, *C*, and *D* the pencil at different distances. The lines drawn from the extremities of the pencil to the eye represent what is called the *visual angle* of the pencil.

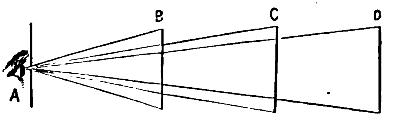

FIG. 150.

The angle formed by the rays of light coming from the extremities of an object to the centre of the eye is called the Visual Angle.

The farther an object is from the eye, the smaller is the visual angle under which it is seen.

IMAGES FORMED THROUGH SMALL APERTURES.

Experiment 144.—Procure a pasteboard box seven inches long, three and a half inches wide, and three inches

deep, or as near these dimensions as possible. Make the inside black by using ink. Construct a little screen (Fig. 151) with pins and pasteboard, and of a size that can be moved from end to end of the closed box. Over the hole in the screen paste smoothly a piece of white tissue paper. Now in the centre of the ends of the box make two smooth holes the size of a common lead-pencil. Over one of the holes paste a piece of tin foil, and through this make a pin-hole. Set the screen in the middle of the box and put on the cover. Now hold the pin-hole towards some object, as a house, a steeple, or a tree, and look through the other hole. You will see an *image* of the object. Move the screen backward or forward till you get the clearest image. In what position is the image compared with the position of the object?

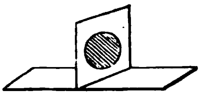

FIG. 151.

Take the box into a dark room. Light a candle. Look through the large hole at the image of the candle. In what position is the image compared with the position of the candle? Can you explain the position of the image by remembering the law of light stated in Exp. 139?

Make a diagram to illustrate your explanation.

REFLECTION OF LIGHT.

Experiment 145.—Hold a piece of looking-glass so that the sun's rays falling upon it will appear as a light spot on the wall.

The spot of light on the wall has been reflected there by the bright surface of the looking-glass.

The rays of light which fall upon the glass are called

incident rays; the rays which the looking-glass sends off to the wall are called the *reflected rays.*

Move the piece of looking-glass so that the angle made by the incident and the reflected rays shall be a very small one. Move the glass so that these rays shall make a very large angle with each other.

Experiment 146.—Make out of cardboard a semicircle having a radius of about twelve inches, like that shown in Fig. 152. Support the cardboard in a vertical position by two pieces of wood in which slots are cut. Directly under the centre of the semicircle place a piece of looking-glass. See that the wooden supports are low enough to let the cardboard touch the glass. The radius marked 0° is perpendicular to the plane of the glass. Now with black paint or liquid shoe-blacking, black either the outside or the inside of a piece of glass tubing nine or ten inches long.

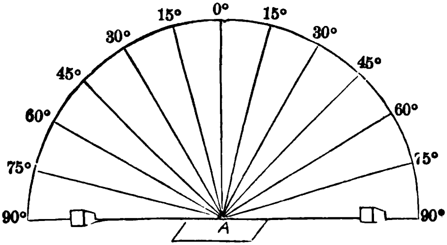

FIG. 152.

Set the apparatus where there is plenty of light, though not in the direct rays of the sun. Select a pin with a large bright head. Thrust the pin through the semicircle, near the outer end of one of the lines—for first trial the one making an angle of forty-five degrees with the radius marked 0°, which is a perpendicular to the surface of the glass. Place the tube on the other side of the perpendic-

ular, with the lower end at A, and find at what angle it must be held in order to see the image of the pin-head.

How do the two angles compare?

Move the pin-head nearer the perpendicular, and find at what angle the tube must be held.

How do the two angles compare?

Move the pin-head farther from the perpendicular. Find the angle at which its image may be seen by looking through the tube.

How do the two angles compare?

Were we to put a small taper in place of the pin-head, we should obtain the same results.

Terms.—The ray from the candle to the mirror is the *incident* ray, and the angle the ray makes with the perpendicular is called the *angle of incidence*. The ray from the mirror is called the *reflected* ray, and the angle which this ray makes with the perpendicular is called the *angle of reflection*.

When rays of light are reflected, the angle of incidence is always equal to the angle of reflection.

DIFFUSION AND ABSORPTION.

Experiment 147.—Procure a piece of looking-glass, two pieces of tin, and a piece of unsized white paper. Blacken one piece of tin by smoking its surface with a candle. Darken a room, and allow a small beam of sunlight to shine in. Hold successively in the beam the looking-glass, the bright piece of tin, the piece of drawing paper, and the piece of blackened tin, and try to reflect the beam of light from each.

Compare the spot of light made upon the wall by the mirror with that made by the piece of tin. Does the mirror or the piece of tin reflect the more light? Why? Try the piece of paper. Can you get a distinct spot on the wall by holding the paper in the beam? Which can you see the more plainly when held in the beam, the looking-glass or the paper? Which illuminates the room the more? Try the piece of blackened tin. Does it reflect any light? Can you see the piece of blackened tin easily?

The looking-glass and the tin reflected light regularly, and are therefore good reflectors. The paper reflected the light irregularly, or *diffused* it. The piece of blackened tin *absorbed* the light.

The experiment shows *reflection*, *diffusion*, and *absorption* of light.

VIRTUAL AND REAL IMAGE.

Experiment 148.—Take the box used in Exp. 144 into a dark room, place a candle in front of the box, and observe the image which appears on the screen inside the box. Next place the candle in front of a looking-glass and observe the image. Wherein do the two images differ? Is there an image on the screen? Is there actually an image behind the looking-glass?

An image that may be thrown upon a screen is called a Real Image.

An image that appears behind a reflecting surface, and that cannot be thrown upon a screen, is called a Virtual Image.

THE POSITION AND DIRECTION OF AN IMAGE BEHIND A PLANE MIRROR.

Experiment 149.—Upon any smooth, flat surface, as the top of a table, draw a line about one foot long. Upon this line, and perpendicular to the surface of the table, support an oblong piece of looking-glass of any convenient size. About six inches out from the glass stick a large bright pin, *P*, into the table so that it shall be perpendicular to the surface of the table. Six or seven inches from the first pin stick another pin, P^2, so that it shall make a straight line with the first pin and its image in the mirror. On one side of *P* and P^2 place two other pins, P^3 and P^4, so that they shall be in a straight line with the image of the first pin set up. Now remove the mirror, and draw lines through the points where the pins stick, producing these lines till they meet behind the mirror. Measure the distance the image *I* was behind the mirror, and compare it with the distance the first pin was in front of the mirror.

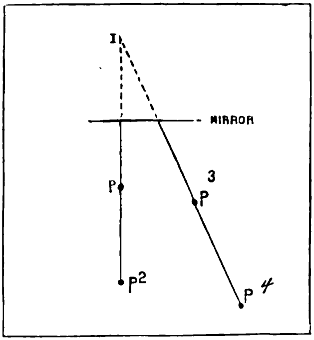

Fig. 153.

The image of an object appears as far behind a plane mirror as the object is in front of it. The image is the same size as the object.

Experiment 150.—Set the mirror up again, and also pins *P* and P^2. Place the eye at the edge of the table,

and look along the line marked by pins P^3 and P^4. Remove these pins. The image of pin P is seen behind the mirror, and in the direction along the reflected ray.

An object when seen by reflection appears in the direction in which the reflected rays enter the eye.

INCLINED MIRRORS.

Experiment 151.—Take two oblong pieces of looking-glass about three by four inches, and paste carefully upon the back a piece of cloth for a hinge. Set these up on the table so that they open at an angle of ninety degrees. Place a candle or other object between the mirrors. Count the number of images. Set the mirrors at an angle of sixty degrees. How many images are seen? Set them at an angle of forty-five degrees. How many images are seen?

What relation is there between the number of degrees the mirrors are inclined, the number of images (counting the object as if it were an image), and three hundred and sixty degrees?

Two mirrors are inclined at an angle of thirty degrees. How many images are formed?

At an angle of one hundred and twenty degrees, how many images are formed?

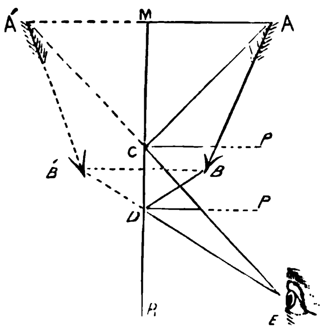

Fig. 154.

How to draw the Image of an Object.—Let A B be an object placed before the mirror M R, and E the place of the eye. Every point of the arrow sends out rays of light in every

direction. Select the extreme points A and B. From the great number of rays which A and B send out, a few only can enter the eye. Let $A\ C$ be one ray from the point A, and $B\ D$ be one ray from the point B, falling so that after reflection they will enter the eye. At the points of incidence C and D erect the perpendicular $C\ P$ and $D\ P$. From C draw the line $C\ E$ so that the angle of reflection will be equal to the angle of incidence. From D draw the line $D\ E$ so that the angle of reflection will be equal to the angle of incidence. Extend the lines beyond the mirror. From the points A and B draw lines perpendicular to the mirror, and extend them behind, a distance equal to their length from the mirror. The points A' and B' are the extreme points of the virtual image.

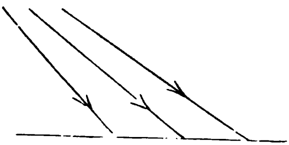

FIG. 155.

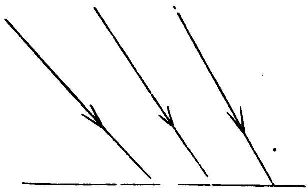

FIG. 156.

Construct a diagram to show what effect a plane mirror has upon divergent rays (Fig. 155). Upon convergent rays (Fig. 156).

CONCAVE AND CONVEX MIRRORS.

Experiment 152.—Procure two watch crystals. Cover evenly the inside of one and the outside of the other with black paint.

These are to be used for mirrors. If you can obtain a hollow concave glass reflector, coated inside with quicksilver, such as is placed behind a bracket-lamp, it will answer the purpose better.

Place in front of a concave mirror (the watch crystal painted on the convex side) a lighted candle or other object. How does the size of the image compare with the size of the object?

Hold a small piece of white paper in front of the mirror, and see if you can throw an image of the candle upon it. Is the image formed by a concave mirror *real* or *virtual?*

Experiment 153.—Place in front and near a convex mirror (the watch crystal painted on the concave side) a lighted candle. How does the image compare in size with the object?

Remove the candle slowly farther and farther away, observing the image all the time. At the greatest distance at which you can see an image of the candle, what changes have taken place?

See if you can throw the image of the candle produced by a convex mirror upon a screen.

What kind of an image is formed by a convex mirror, real or virtual?

Notice the images formed in a brightly polished tablespoon, the outside of the bowl being regarded as a convex mirror, and the inside as a concave mirror.

REFRACTION.

Experiment 154.—Procure a large rectangular-shaped bottle of uncolored glass. Fill this bottle with water, and place it on a table in a darkened room. With a *porte lumière* (see Appendix, § 5) send a beam of light so that it will strike the side of the bottle perpendicularly. Scatter

a little crayon dust through the air about the bottle, by clapping together two blackboard erasers, and you will notice that the course of the ray through the water is in a straight line with the course of the ray outside of the bottle (Fig. 157).

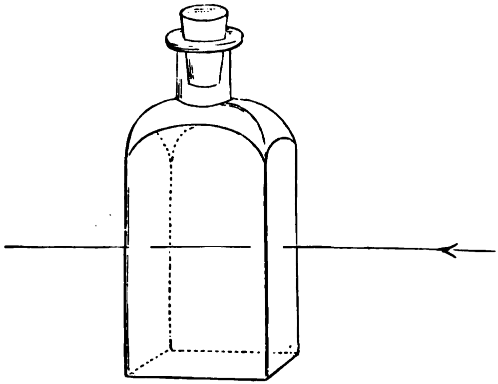

Fig. 157.

Turn the mirror of the *porte lumière* slightly, so that the ray will fall obliquely upon the side of the bottle. Put a piece of black paper on one side of the bottle, so that the direction of the ray through the water may be more easily seen. You notice now that the ray is bent out of its course.

Scatter a little crayon dust about the bottle, and notice the direction of the ray as it leaves the water. Here again it is bent out of its course.

Which way was the ray bent as it entered the water, referring to its direction before entering? Which way after leaving the water, referring to its direction through the water?

When the ray fell perpendicularly upon the side of the bottle, or surface of the water against the side, its course was not changed. When it fell upon the side of the bottle obliquely, it was bent out of its course, or *refracted.*

Not regarding the thin glass of the bottle, the ray of light passed through two media, air and water.

The bending of a ray of light out of its course when it passes from one medium to another is called Refraction.

To draw the Directions of Incident and Refracted Rays.— If the experiment was carefully made, *R I O Y* in Fig.

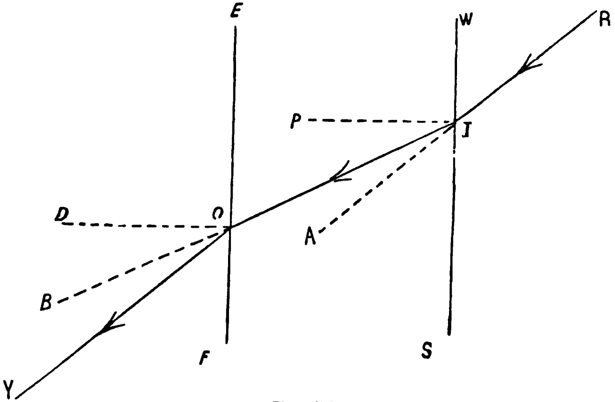

Fig. 158.

158 will represent the direction of the ray. The point *I*, where the ray fell upon the surface of the water, is the *incident point*, and *R I* is the *incident ray; I O* is the *refracted ray*, and *O Y* is the ray after a second refraction. At the point *I* and in the medium the ray is entering, draw a perpendicular *P I* to the surface *S W*. Had the ray not been refracted out of its course, it would have gone in the direction *I A*. It took, however, the direction *I O*, and was refracted, in going into a more refractive medium, toward the perpendicular *P I*.

At the point *O* and in the medium the ray is entering, erect the perpendicular *D O* to the surface *F E*. Had

the ray not been refracted, it would have continued in the direction *O B*. But upon entering the less refractive medium, it was refracted away from the perpendicular *D O*.

When a ray of light passes perpendicularly from one medium to another, it is not refracted.

When a ray of light passes obliquely from a less refractive to a more refractive medium, it is refracted toward the perpendicular.

When a ray of light passes obliquely from a more refractive to a less refractive medium, it is refracted from the perpendicular.

The incident ray, the refracted ray, and the perpendicular are in the same plane.

Experiment 155.—Repeat the previous experiment, using instead of the bottle of water an oblong glass paper-weight, if one can readily be obtained. Stand the paper-weight on end, and let the ray enter one of the narrow sides. Compare the refractive powers of glass and water.

Place a coin in a dish ; put the eye in a position so that the farthest edge of the coin may just be seen above the edge of the dish. Hold the eye in the same position, and let some one pour water into the dish, not disturbing the coin. Explain what you observe.

TOTAL REFLECTION.

Experiment 156.—Take the bottle filled with water that was used in Experiment 154, and support it as shown in Fig. 159. With the *porte lumière* direct a strong beam of light under the bottle. With a mirror (see Fig. 159)

reflect the beam so that it will strike the side of the bottle perpendicularly. Note that it is not refracted as it passes

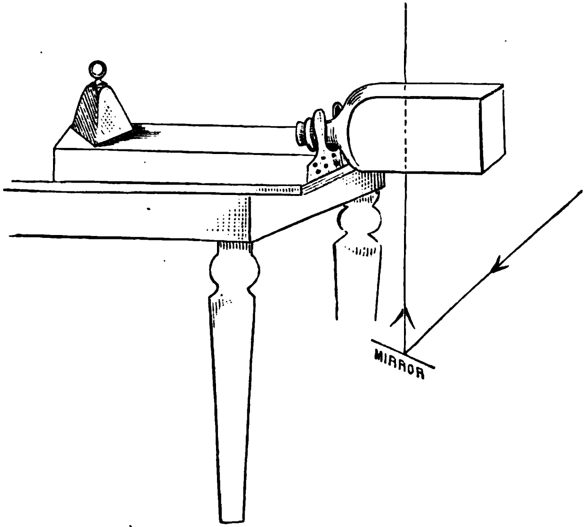

FIG. 159.

through the water. Now turn the mirror so that the beam will strike the lower surface of the water obliquely. Notice how much it is refracted as it passes out of the water into the air. Turn the mirror so that the beam will strike the lower surface of the water more and more obliquely. Notice carefully the amount of refraction. Diffuse a little crayon dust through the air. As the beam strikes more and more obliquely, you will observe that at one point it is refracted almost parallel to the surface of the water. When it strikes a little more obliquely, the beam does not pass through the water, but is reflected from its upper surface. This reflection is called *total reflection.*

Experiment 157.—Put a spoon in a glass of water. Raise the glass above the eye, and look at the surface of the water. The surface looks like polished silver, because all the light is reflected. A part of the spoon is distinctly seen by total reflection.

Fig. 160.

A ray of light is totally reflected when, in passing through a more refractive medium to a less refractive one, it strikes the surface at such an angle as to be reflected back instead of being refracted.

PRISMS AND LENSES.

Experiment 158.—Hold a glass prism in the position shown in Fig. 161, and look at a lighted candle. The candle appears higher up than it actually is. Let us follow one ray from

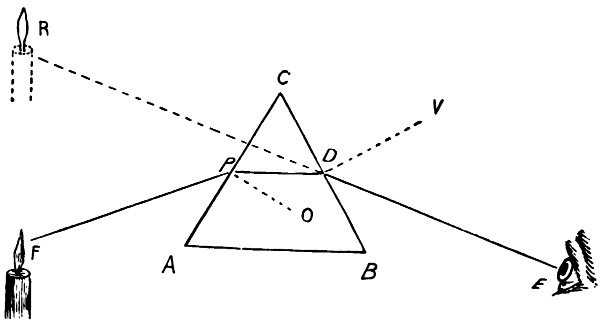

Fig. 161.

the candle to the eye. The ray *F P* strikes the prism obliquely at the point *P*. Draw the perpendicular *P O*

from the incident point and in the refracting medium. The ray in passing from a less refractive to a more refractive medium is refracted toward the perpendicular, or in the direction *P D*.

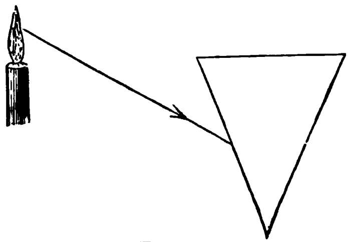

Fig. 162.

At *D* the ray passes again to a less refractive medium, and is refracted away from the perpendicular *D V*, or in the direction *D E*.

The candle appears at *R*, a prolongation of the direction that the ray entered the eye.

Can you now draw Fig. 162 and complete it, showing where the candle would appear.

LENSES.

Different Kinds of Lenses.—A piece of glass bounded by two curved surfaces, or one curved and one plane surface, is a *lens*.

These are six kinds of lenses :

Thin-edged, thick in the centre.

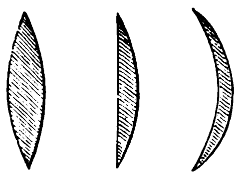

Fig. 163.

1. Double convex—both surfaces convex.
2. Plano-convex—one plane and one convex surface.

3. Concavo-convex converging—one convex and one concave surface.

These three lenses are thickest in the middle, and are called *converging* lenses, because the rays of light after passing through them converge.

Thick-edged, thin in the centre.

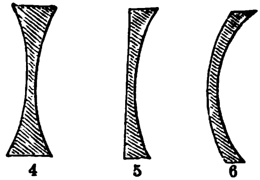

FIG. 164.

4. Double concave lenses—both surfaces concave.
5. Plano-concave—one plane and one concave surface.
6. Concavo-convex diverging—one concave and one convex surface.

These three lenses are thinnest in the middle, and are called *diverging* lenses, because rays of light after passing through them diverge.

Lenses 3 and 4 are sometimes called meniscus lenses. (Meniscus = moon shaped.)

Experiment 159.—Make a temporary collection of lenses by bringing together a reading-glass, the larger lenses from an opera glass or a spy-glass, the lenses from a magic lantern, and the lenses from spectacles. Hold each lens in a horizontal position on a level with the eye, and look across its surface toward the light coming from a window. With a slight movement of the lens, you can tell whether the surface is convex, concave, or plane. Examine both surfaces of each lens, and determine what kind of a lens it is.

Experiment 160.—Hold a double convex lens in the sun's rays. Scatter a little crayon dust under the lens, and notice how the sun's rays are refracted so that they

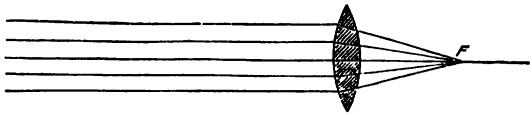

FIG. 165.

converge to one point. This point is called the *focus* (fire-place). (See *F*, Fig. 165.) Hold a piece of black paper at this point. What is the effect?

Look through a double convex lens at any object. Does the lens make the object look larger or smaller? In other words, does the lens *magnify* or *minify?*

Place the lens near the eye so that the object can be quite clearly seen. Move the lens farther and farther from the eye. Does the object always appear in a vertical position?

Place the lens at such a distance from the eye that the object may be clearly seen. Without changing the distance between the lens and the eye, move the object nearer and then farther away. What is the effect?

Experiment 161.—Darken a room, except a part of one window. Let the day be a bright one. Hold the lens near the wall, and then move it out from the wall till an image of the window and what is beyond is thrown on the wall. Stop the lens at that point where the image is clearest. Measure the distance from the wall to the lens. This distance is called the *focal length* of the lens.*

* The distance thus found is the focal length only if the window is far enough from the lens so that the rays of light from the window are parallel as they fall upon the lens.

Is the image thrown on the wall a *real* or a *virtual* image?

Repeat the experiment, using a plano-convex and a concavo-convex converging lens, if these are in your collection of lenses.

Experiment 162.—Darken a room, except a part of one window, as in Exp. 161. Hold a double concave lens near the wall, and then move it out slowly from the wall. Can you obtain an image on the wall as you can when using a double convex lens?

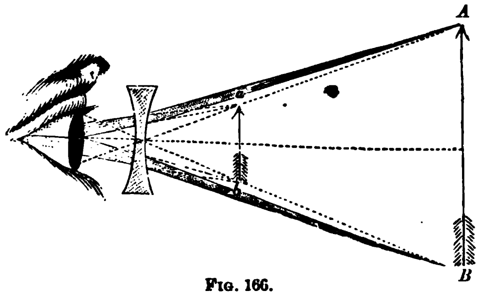

FIG. 166.

Look through the double concave lens at the window or any other object. An image is formed smaller than the object. Is it a *real* or a *virtual* image?

The rays of light from the arrow *A B* (Fig. 166), after passing through the lens, seem to the eye to come from the smaller image *a b*.

COLOR.

Experiment 163.—Over the opening in the *porte lumière* (see Appendix, § 5) put a piece of tin-foil or cardboard having an opening three-quarters of an inch long and one thirty-second of an inch wide, with very smooth edges. Direct a beam of sunlight into a darkened room through this slit.

Place in the beam a prism, with the edges of the prism and the slit parallel. If the wall is not sufficiently near, place a white screen behind the prism.

A band of different colors will appear upon the screen. Such a band of colors is called the *solar spectrum.*

Names of the Colors of the Spectrum.—The spectrum is

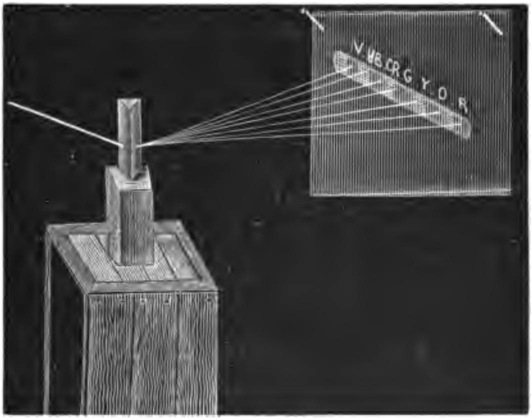

FIG. 167.

composed of a great number of colors, blending one into another. As seven colors can be clearly made out, it is usual to say that the solar spectrum is composed of the seven colors—*red, orange, yellow, green, cyan-blue, ultramarine-blue,* and *violet.* Cyan-blue and ultramarine-blue are

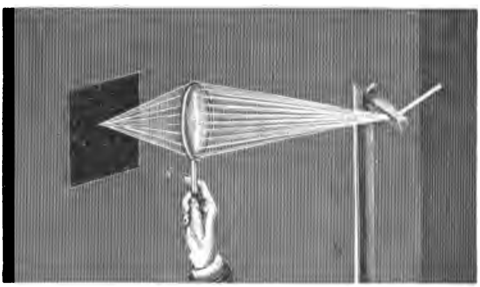

FIG. 168.

the names of blue pigments which very closely resemble the two blues of the spectrum.

Scatter a little crayon dust about the rays, and determine where the sunbeam would have made a bright spot on the screen, if it had not been refracted. Now determine which of the colors is refracted least; which is refracted most.

Experiment 164.—Hold a convex lens in the spectrum (Fig. 168). The colors will be refracted to a focus and recombined to form white light. Cut off the red rays by putting a card between the prism and the lens.

FIG. 169.

What color is the light at the focus? Cut off the blue rays. What color is the light at the focus?

Or, instead of the convex lens, hold a second prism near the first one, with their faces parallel, as shown in Fig. 169. The light coming from the second prism is no longer colored.

Experiment 165.—Place a piece of red ribbon or paper in the red rays of the spectrum. Is it any brighter in the red? Now move it towards the blue. You notice that it grows gradually darker, at last appearing black. In what colors does it appear black?

Place a piece of blue ribbon in the blue rays and move it towards the red. In what color is it blue? In what, black?

Pass a ray of sunlight from the *porte lumière* through a piece of red glass; through a piece of blue glass; through both the red and the blue glass. Does any light pass

through? The red glass absorbs blue light, and the blue glass absorbs red light.

Color of Bodies.—The color of a body is due to its property of reflecting or transmitting rays of a particular kind, the other rays generally being absorbed. If light were not composed of the different colors, there would be no variety of color in objects. Test this by rolling up a ball the size of a marble out of loose cotton twine. Soak this ball in a strong solution of common salt. Let the ball dry, or squeeze out all the brine possible. Wet the ball with alcohol, place it upon a saucer, and set fire to it in a dark room. In the yellow light that is produced, examine pieces of red, yellow, and blue ribbon or paper, or flowers of different colors. They will appear either yellow or black. Why?

MIXING COLORS.

Experiment 166.—Upon a black background (*A*, Fig. 170), place two pieces of colored paper, one yellow and the other ultramarine-blue. Let them be about one and one-half inches apart, and above them hold a piece of window-glass, as shown in Fig. 170. When the eye is held in the position indicated, the light from the yellow paper will be reflected from the nearer side of the glass, and the image will appear close to the blue paper seen through the glass.

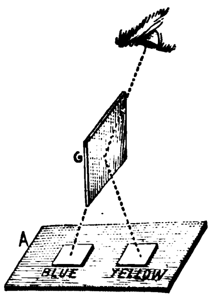

FIG. 170.

By moving the glass a little, the two pieces of colored paper can be made to coincide, but the color then seen will be a grayish white. Caution: if the color has a yellow

tinge, the glass is held too high ; if a bluish cast, the glass is held too low.

Experiment 167.—Procure a top that is spun by a holder (Fig. 171). Next cut out of stiff paper or cardboard seven circular disks four inches in diameter, and color them so that each will represent, as nearly as possible, one of the colors of the spectrum. In the centre of each disk make a hole just large enough to slip snugly over the spindle of the top. Cut a straight slit from the circumference to the centre of each disk.

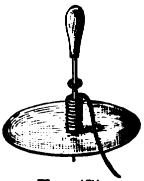

FIG. 171.

Place together, by means of the slits, a yellow and an ultramarine-blue disk, as in Fig. 172. In this position put them on the spindle of the top, and spin the top. The rapid motion causes the sensations produced by the two colors to be blended together in the eye, and we see but one color. If the right proportion of each disk has been left visible, this color is grayish white.

FIG. 172.

Any two colors that together produce white are called Complementary Colors.

Experiment 168.—Put the red, the green, and the violet disks together (Fig. 173), allowing less of the green to be exposed than of the other two. Rotate these. You should obtain grayish white. Try the same thing with red, green, and blue disks. Try combining any color with the two that are opposite to it in Fig. 174.

Third, combine green and violet, first allowing more of

the violet to show, and then more of the green. Can you obtain the colors between them in Fig. 174? In like manner mix green and red in varying proportions. What colors result?

Now try to make green, red, and violet by mixing any of the other colors together. What is the result?

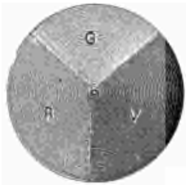

Fig. 173.

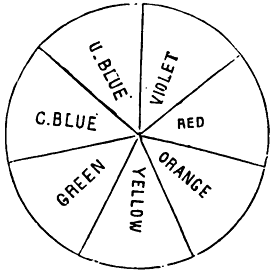

Fig. 174.

Since we can obtain the whole spectrum from green, violet, and red, but cannot obtain these colors by mixing any others, green, violet, and red are called *primary* colors, and the others are called *secondary* colors.

COLORED PIGMENTS.

Experiment 169.—Mix a little of the yellow and blue pigments with which you have colored the disks. What is the color of the pigment that you obtain? Next fill a flat bottle with water, and color it with a little blue vitriol. In a similar bottle color water yellow with bichromate of potash.

In a darkened room, throw a solar spectrum upon a screen, and between the prism and the screen interpose the bottle containing the blue liquid. The green, cyan-blue, ultramarine-blue, and violet rays are still visible on the screen, but the red, orange, and yellow rays are cut off; that is, they are absorbed by the blue liquid. Removing the bottle of blue liquid, interpose in the same way the bottle containing the yellow solution. Now the red,

orange, yellow, and green rays are allowed to pass, but the cyan-blue, ultramarine-blue, and violet rays are cut off.

Next place the two bottles side by side in the spectrum, so that the rays from the prism will have to pass through both in order to reach the screen. What color is visible on the screen? What rays are now intercepted? We may express these results as follows:

	Colors of the Spectrum
Absorbed by the blue solution:	~~R~~, ~~O~~, ~~Y~~, G, U-B, C-B, V.
Absorbed by the yellow solution:	R, O, Y, G, ~~U-B~~, ~~C-B~~, ~~V~~.
Absorbed by the two solutions:	~~R~~, ~~O~~, ~~Y~~, G, ~~U-B~~, ~~C-B~~, ~~V~~.

This explains what occurred when we mixed the blue and yellow pigments together. Just as the solutions in the bottle absorbed some rays and transmitted others, so the pigments absorbed some rays and reflected others. The blue pigment absorbed the red, orange, and yellow rays; the yellow pigment absorbed the cyan-blue, ultramarine-blue, and violet rays. Hence the only rays not absorbed, namely, the green rays, were reflected to the eye.

But in Exp. 168 we did not mix the materials that gave the color, we mixed only the color sensations in the eye. Hence, the very rays absorbed by the blue paper were supplied by the reflected image of the yellow paper, and consequently we saw all seven rays of the spectrum, or white.

THE RAINBOW.

How the Rainbow is formed.—A drop of water acts upon a ray of sunlight just as a prism does, decomposing it into the seven prismatic colors. This action of the rain-drop may be understood by Fig. 175, which represents a section

of two drops. *S S* are two parallel rays of sunlight falling upon the drops of rain at *a*. Each ray is refracted to *b*, where some of the light passes out of the drop toward *x*; but the remainder is reflected from the inner surface of the drop and passes out at *c*, undergoing a second refraction. In its course through the rain-drop, the light is decomposed, the violet rays being refracted more than the red rays (see p. 195). If, then, the red rays from the upper drop enter the eye of an observer at *E*, the violet rays from this drop will pass over his head. The violet that he sees comes from a lower drop of water, as shown in

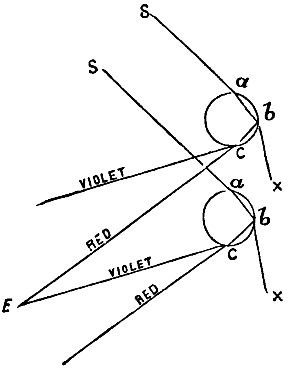

FIG. 175.

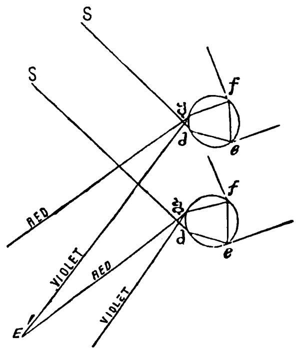

FIG. 176.

Fig. 175, while the red rays from this second drop fall at his feet. Other drops of rain between the two represented supply the other colors of the spectrum.

When the colors are seen in the order indicated in Fig. 175, the bow is called a *primary* bow.

A fainter or *secondary* bow is often seen above the primary bow. This is caused by other rays of sunlight (*S S*, Fig. 176), which fall at *d d* on the lower side of rain-drops higher up than those that produce the primary bow. From *d* the ray is refracted to *e*; at the point *e* a part of it is

reflected to f, and thence a still smaller portion is reflected to g. At g the ray is again refracted, and the colors into which the ray has been decomposed by the drop pass into the air.

Explain from the figure why the colors of the secondary bow are in the reverse order to those of the primary bow. Can you tell why the secondary bow is fainter than the primary bow? Would an observer standing on the roof of a house and another observer standing on the ground see the same rainbow?

THE VELOCITY OF LIGHT.

First discovered by Rœmer.—The velocity with which light travels through space was first discovered by Rœmer, a Danish astronomer, in 1676, in observing the eclipses of the first satellite, or moon, of the planet Jupiter. This satellite revolves around Jupiter in forty-two hours, twenty-eight minutes, and thirty-six seconds. Now Rœmer observed that as the earth moved in its orbit toward Jupiter, or from F to N (Fig. 177), the intervals between the suc-

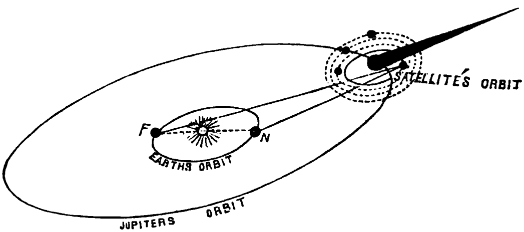

FIG. 177.

cessive times this satellite entered the shadow of Jupiter, or was eclipsed, grew shorter; and that as the earth was moving away from Jupiter, or from N to F, the intervals between successive eclipses grew longer.

When the earth was at N, Rœmer found that the eclipse took place sixteen minutes and thirty-six seconds earlier

than if the earth had been at *F*; and that when the earth was at *F*, the eclipse took place sixteen minutes and thirty-six seconds later than if the earth had been at *N*. He therefore reasoned that this difference was due to the time it takes light to travel from *N* to *F*, which is the diameter of the earth's orbit.

This distance is one hundred and eighty-six million miles. If we reduce sixteen minutes and thirty-six seconds to seconds, and divide one hundred and eighty-six million miles by the number, the velocity of light per second will be obtained. Other methods for determining the velocity of light have been found.

These results show that the velocity of light is about 186,000 miles per second.

OPTICAL INSTRUMENTS.

The Simple Microscope.—A double convex lens of short focal length is called a *simple microscope*. The eye is

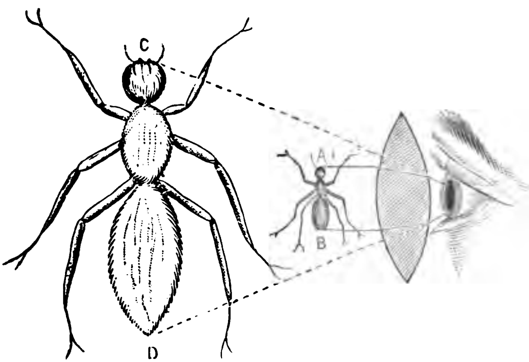

FIG. 178.

placed close to the lens and the object at a distance less than the focal length of the lens. This distance varies for different persons.

The image is virtual and erect.

In Fig. 178 *A B* is the object, and *C D* the image.

Compound Microscope.—The compound microscope consists of two or more convex lenses mounted in a tube, which is blackened inside. One of the lenses is of short focus and is called the *objective;* the other lens is of longer focal length and is called the *eye-piece.* The object *A B* (Fig. 179) is placed just beyond the focus of the objective *O*. A real inverted image *C D* is formed within the tube.

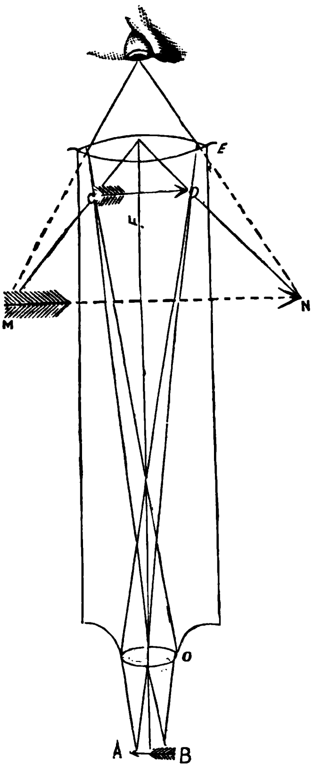

FIG. 179.

The eye-piece *E*, a lens of greater focal length, is used to examine the image *C D*. The lens *E* is so placed that the real image lies between the lens and its focus *F*.

A virtual image *M N*, greatly magnified, is seen by the eye.

THE ASTRONOMICAL TELESCOPE.

Experiment 170.—Take a large lens of ten or twelve inches focal length (see Exp. 161). Cut a groove in a cork, and press the edge of the lens into this groove, thus making a temporary holder for the lens. Stand this lens upon a table in a darkened room, and place at as great a distance

as possible a lighted candle (Fig. 180). Place behind the lens the screen used in Exp. 144.

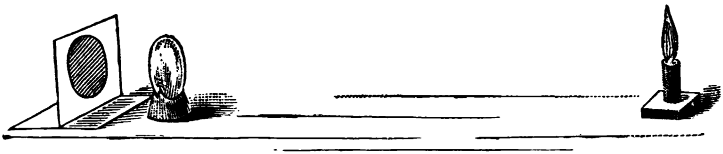

FIG. 180.

See that the middle part of the candle flame and the centres of the lens and screen are on a level. Now move the screen back from the lens until an inverted real image, smaller than the candle, is formed on the screen. Remove the screen, and put in its place a convex lens of short focal length mounted on a cork. Look through this lens, and a magnified upright virtual image will be seen.

If these lenses were placed in tubes blackened inside, and made to slide the one into the other, a common astronomical telescope would be formed.

Explanation.—In Fig. 181, *A B* is an object very far distant, *O* is the objective. Rays from the extremities of the object are refracted by the objective, and a real inverted image *C D* is formed. The eye-piece *E* magnifies the real image *C D*, and the eye sees the virtual image *M N*.

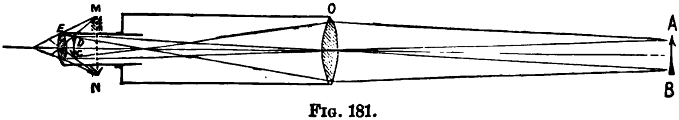

FIG. 181.

The object *A B* being at a great distance, an inverted image is seen. This inversion is not found inconvenient when examining the heavenly bodies.

Experiment 171.—Throw an image upon the screen, as in the previous experiment. Remove the screen, and put in its place a double concave lens mounted on a cork. Now move the concave lens slowly towards the convex lens until the eye sees an erect enlarged image of the candle. It is better to fasten to the cork, with a pin, a piece of pasteboard with a hole through it half the diameter of the lens. This piece of pasteboard may be regarded as a *diaphragm*, and should be on the side of the cork next to the eye.

Were these lenses set in sliding tubes of proper size, the *Galilean telescope* would be formed.

The Opera Glass.—The opera glass consists of two small Galilean telescopes placed side by side.

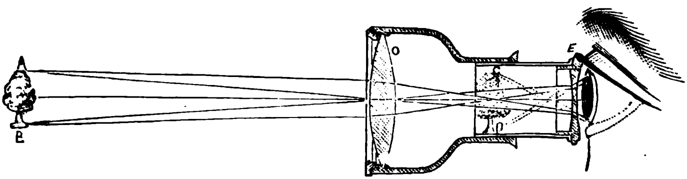

FIG. 182.

In Fig. 182, *A B* is the object, *O* the objective, and *E* the eye-piece. The rays from the extremities of *A B* converge after their refraction by the objective *O*, and are rendered diverging after their refraction by the eye-piece *E*. Thus the rays appear as if they came from *C D*. The image is erect.

THE CAMERA.

Explanation.—In Exp. 144, by letting the light from an object shine through a pin-hole in the end of a dark box,

an image of that object was obtained on a sliding screen. The photographer's camera is like the pin-hole camera (Exp. 144). The only essential difference is that in place of a pin-hole a

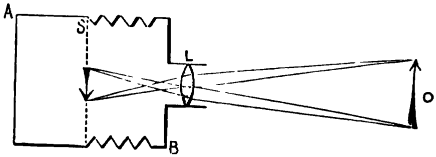

FIG. 183.

double convex lens (*L*, Fig. 183) is used. The movable screen *A* is made of ground glass. The rays coming from an object *O* form an inverted image, clear in outline, at *S*, and the movable screen *A* is pushed up to this point, so that the image may be examined by the eye. To secure a picture of the object, a sensitized plate is put in the place of the screen and exposed to the rays of light that come from the object. These rays produce certain chemical changes in the plate, imprinting there a picture of the object.

THE EYE.

The Eye a Camera.—Fig. 184 represents a section of the human eye. It has for its outer wall a tough membrane called the *sclerotic* coat. Inside of this coat is a delicate membrane called the *choroid* coat. The choroid coat is dark in color, which prevents internal reflection of the rays that enter the eye.

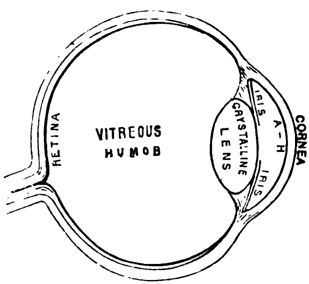

FIG. 184.

The third and inner coat of the eye is the *retina.* It is a very thin, translucent membrane, at the back part of the eye, formed by the expansion of the *optic nerve,* and is very sensitive to light.

When the light falling upon an object is not reflected or diffused, it is said to be absorbed.

A real image is an image that is actually formed.

A virtual image is an unreal, or apparent, image.

Refraction is a change in the direction of a ray of light when it passes obliquely from a less refractive to a more refractive, or from a more refractive to a less refractive, medium.

Laws of Refraction. I.—When a ray of light passes perpendicularly from one medium to another, it is not refracted.

II.—When a ray of light passes obliquely from a less refractive to a more refractive medium, it is refracted toward a perpendicular at the point of incidence.

III.—When a ray of light passes obliquely from a more refractive to a less refractive medium, it is refracted from the perpendicular.

IV.—The incident ray, the refracted ray, and the perpendicular are in the same plane.

A ray of light is totally reflected when, in passing through a more refractive medium, it strikes the surface of a less refractive medium at such an angle as to be reflected back, instead of being refracted.

The convex lenses collect rays of light to a focus, and so magnify the objects seen through them.

The concave lenses scatter rays of light, and apparently diminish the size of the object.

A prism decomposes a ray of sunlight into seven colored rays: red, orange, yellow, green, cyan-blue, ultramarine-blue and violet. These colors, when thus formed, are called the solar spectrum.

The color of a body is due to its property of reflecting, or transmitting, rays of only a particular kind.

The primary colors are red, green, and violet. The other colors of the spectrum are called secondary colors.

Complementary colors are any two colors that together produce white light.

The rainbow is caused by the reflection and the refraction of rays of sunlight by drops of rain.

The velocity of light is about one hundred and eighty-six thousand miles per second.

Questions.

1. What are luminous bodies ?

2. Distinguish between transparent, translucent, and opaque bodies.

3. What is a shadow ?

4. Explain how the umbra is formed. How the penumbra.

5. Can any part of a luminous body be seen from the penumbra ?

6. What effect has distance upon the intensity of light ?

7. Explain why the images seen through small apertures are inverted.

8. Show by a diagram what is meant by the statement, the angle of incidence always equals the angle of reflection.

9. In what respect does a real image differ from a virtual image ?

10. Draw a diagram to show the way in which an image is formed by a plane reflecting surface.

11. Explain why several images are sometimes seen when an object is seen by reflection in a thick glass mirror. Which image is the brightest ? Why ?

12. What is diffusion of light, and how does it differ from reflection and absorption ?

13. What relations does the image formed by a plane mirror bear to the object ?

14. Under what conditions will a ray of sunlight not pass through a prism ?

15. Two mirrors are inclined at an angle of 30° ; how many images of an object placed between them are seen ? At 120° ?

16. Is the image formed by a convex mirror larger or smaller than the object ?

17. Under what conditions is the image formed by a concave mirror larger than the object ? Under what conditions is the image smaller ?

18. What laws are obeyed when a ray of light passes from one medium to another ?

19. Name and classify the different kinds of lenses.

20. How can you ascertain the focal length of a lens ?

21. What is the solar spectrum ?

22. Name in order the colors of the solar spectrum, beginning with the color most refracted. Name the colors beginning with the one least refracted.

23. What are complementary colors ?

24. How did Rœmer determine the velocity of light ?

25. Name the colors of the primary rainbow, beginning with the color on the under side of the arch. Name the colors of the secondary bow.

26. How many refractions and reflections in each of the rain-drops which produce the secondary bow? How many in each of the rain-drops producing the primary bow?

27. Draw a diagram to show how the colors of the spectrum are produced by a drop of dew in the sunlight.

28. What is the most common cause of near-sightedness? What of far-sightedness? What kind of glasses are required for the former? What for the latter? Why?

CHAPTER IX.

MAGNETISM AND ELECTRICITY.

Magnets.—A body which has the property of attracting iron is called a magnet.

There is a particular kind of iron ore called lodestone, found principally in Siberia and Scandinavia, that has the power of attracting iron. These pieces of ore are *natural magnets.*

Lodestone was originally found in Magnesia, Asia Minor, whence the name *magnet* and *magnetism.*

If a bar of steel be rubbed against lodestone, it will become magnetic. Such a magnet is called an artificial magnet.

Experiment 172.—Rub against a bar magnet (see Appendix, § 3) a knife-blade or any other piece of steel. Bring the knife-blade near iron filings or small tacks. Has the blade acquired magnetic properties?

Experiment 173.—Take the bar magnet used in the previous experiment, and lay it down upon a sheet of paper. Sprinkle iron filings over the whole length of the magnet. Now take hold of the middle part of the magnet and lift it out of the iron filings.

To what part of the bar magnet do the iron filings cling?

The ends of a magnet where the attraction is greatest are called its *poles.*

Notice that the attraction of the magnet for iron filings diminishes from the poles towards the centre of the bar, where it is nothing. This central line is called the *equator*, or *neutral line*, of the magnet.

Experiment 174.—Sprinkle iron filings evenly over a sheet of paper, one edge of which is fastened to the edge of the table with two pins, while the other edge is held in the hand. Bring the end of the bar magnet against the under surface of the paper, and move the magnet about.

Note the results.

Now perform the same experiment, using cardboard instead of paper. Next use a piece of glass. Last try a piece of board an inch thick.

The power exhibited by a magnet at its poles is called *magnetic force.*

The space through which the influence of a magnet extends is called the *magnetic field* of that magnet.

Experiment 175.—Lay a bar magnet upon the table, and put over this a sheet of paper. To keep the surface of the paper level, lay on the desk, about three inches on each side of the magnet, two strips of wood the thickness of the magnet. When you have made the surface of the paper level, sprinkle carefully fine iron filings over the paper. Tap the paper gently. Notice closely the way in which the filings arrange themselves. Make a careful sketch of these. Put the magnet between two books so that it may stand edge up. Lay a sheet of paper over the magnet, sprinkle iron filings on this, and make a careful

sketch to represent the way the iron filings arrange themselves.

Stand the magnet on end, lay a sheet of paper over the end, sift iron filings upon the paper, and make a sketch of the arrangement of the filings.

The lines in which the iron filings arrange themselves represent the *lines of force* radiating from the magnet

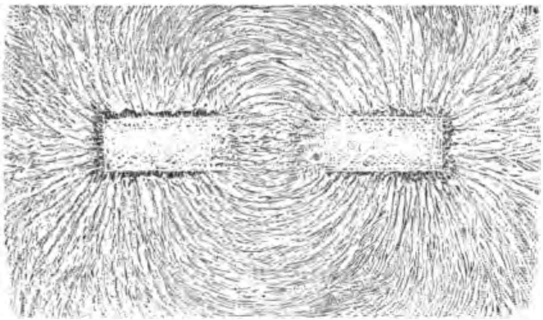

Fig. 186.

(Fig. 186). From what part of the poles of the magnet were the lines of force the greatest? In which of the three positions did the lines of force appear straight lines? In which, curved lines?

edges of sides

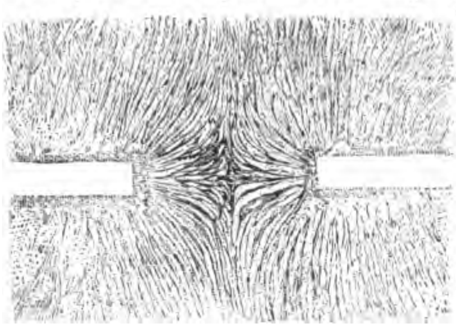

Fig. 187.

Fig. 187 shows how the filings will arrange themselves when two similar poles are held near each other.

Experiment 176.—Take two steel knitting needles of the same size, and tie tightly around the end of each needle, in order to mark that end, a piece of colored silk or thread. Lay the needles parallel to each other on the table, with the marked ends together.

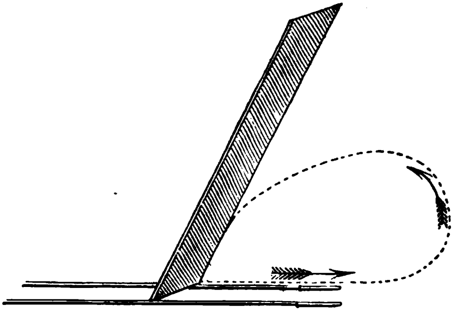

FIG. 188.

Now magnetize the marked ends, by putting one pole of the bar magnet upon the middle part of the needles and drawing it towards the ends. Repeat this movement several

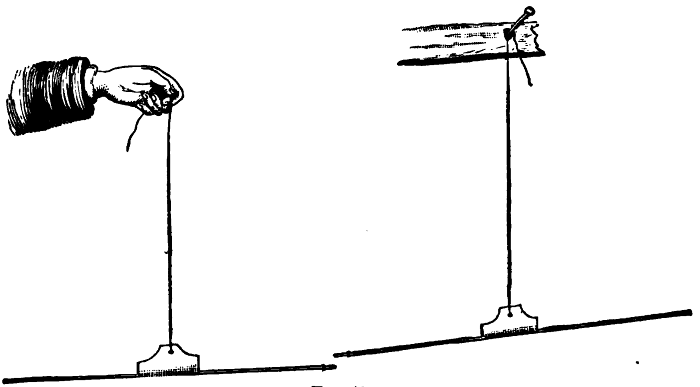

FIG. 189.

times in the manner indicated in Fig. 188. When you have finished, remove the bar magnet several feet from the needles.

As the marked ends of the knitting needles have been magnetized in the same manner, they ought to possess the same kind of magnetism.

Place one of the needles in a paper stirrup suspended by a fine silk thread, as shown in Fig. 189. Place the other needle in a paper stirrup, and hold the silk thread in the hand. Bring the two marked poles of the needle very near each other. What is the effect? Repeat until you are sure about the effect.

Put the two knitting needles on the table in the same position as when you magnetized the marked ends. Magnetize the unmarked ends by taking the other pole of the bar magnet, placing it upon the middle part of the knitting needles, and drawing it out over the unmarked ends. Place the needles in the stirrups, and bring the unmarked poles very near each other. What is the effect?

Now bring the marked pole of one needle near the unmarked pole of the other needle. What is the effect? Try the other marked and unmarked poles of the needles. Is the effect the same?

In different magnets like poles repel each other, and unlike poles attract each other.

Experiment 177.—Bring the pole of the bar magnet, used in magnetizing the marked end of the knitting needle, near the marked end of the needle while suspended, and determine how the magnetism in the marked end of the knitting needle compares in kind with the pole of the magnet. Are these poles like or unlike?

THE MAGNETIC NEEDLE.

Experiment 178.—Suspend one of the knitting needles in one of the paper stirrups. Let it move back and forth till it comes to a position of rest. Take the precaution to remove to a distance all pieces of iron or steel, so that the knitting needle may not be affected by them. In what direction does the knitting needle point? The north-seeking pole of the needle is its *positive* pole, and is marked +. The south-seeking pole is the *negative* pole, and is marked —. Fig. 190 is an illustration of a magnetic needle. It consists of a thin piece of steel, having a hole in the middle, in which is fitted a cap of steel or agate. This cap is balanced on a steel pivot, so that the needle is free to turn in a horizontal plane. The upper part of the figure shows the under side of the needle.

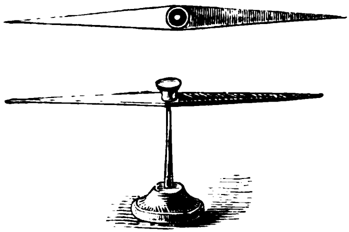

Fig. 190.

Fig. 191.

THE COMPASS.

Variation of Magnetic Needle.—A magnetic needle arranged similar to that in Fig. 190 is adopted in the ordinary portable compass like that shown in Fig. 191.

The magnetic needle does not point exactly north and south, but towards the magnetic north and south poles of the earth.

Look on the map of North America in almost any geography, and you will find the north magnetic pole in about longitude 95 west, and latitude 70 north. The direction in which the magnetic needle points also varies slightly from year to year. Taken over centuries, it varies considerably.*

The angle which the magnetic needle makes with the meridian is called its Declination.

Experiment 179.—Suspend the heaviest possible key or piece of soft iron from the north pole of a bar magnet (Fig. 192), and then slide another bar magnet above the first, with the north pole approaching the

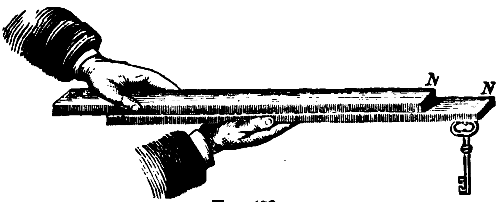

Fig. 192.

* The declination of the magnetic needle, which varies in different places, is at present west in Europe and in Africa, but east in Asia and in the greater part of North and South America. It shows further considerable variations even in the same place.

In certain parts of the earth the magnet coincides with the geographical meridian. These points are connected by an irregularly curved imaginary line, called *a line of no variation*. Such a line cuts the east of South America, and, passing east of the West Indies, enters North America near Philadelphia, and traverses Hudson's Bay ; thence it passes through the north pole, entering the Old World east of the White Sea, traverses the Caspian, cuts the east of Arabia, turns then towards Australia, and passes through the south pole, to join itself again.—*Ganot.*

north pole of the magnet supporting the key. Observe the result.

Again suspend the key from the north pole of the bar magnet, and then slide the other bar magnet above the first, with the south pole approaching the north pole of the magnet which supports the key. Make several trials, using the opposite poles of bar magnets.* Observe the results. State under what conditions the key will drop, and under what conditions it will be held by the magnet. Suspend the key under the north pole, and bring the south pole of the other bar magnet against the end of the magnet supporting the key (Fig. 193). What is the result?

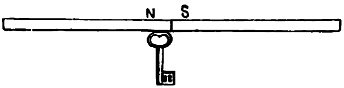

FIG. 193.

Again support the key, and bring up end to end the north pole of the other bar magnet. What is the result?

Experiment 180.—Find how great a weight may be supported from one pole of a bar magnet. Lay one bar magnet upon the other, so that the north pole of the one may be above the north pole of the other, and determine whether the two magnets will support any greater weight than one. Make several careful trials, and state your conclusions.

Experiment 181.—Put a magnetized knitting needle upon the table, and sprinkle iron filings over the needle. Lift it carefully. The iron filings cling only to its ends, or poles. Remove the filings, and cut the needle in two at the middle point. Put both parts in iron filings.

* If two bar magnets are not at hand, file into two equal lengths a knitting needle, magnetize both parts, and use a lath nail instead of the key.

Determine the polarity of the ends of each part. Make a drawing of what you have observed, following in your drawings the arrangement suggested in Fig. 194.

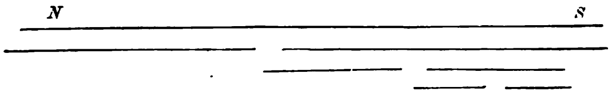

FIG. 194.

Remove the iron filings, divide one half of the needle into two equal parts, and dip these parts in iron filings. Make a drawing to illustrate what you have observed. Divide one of the fourths into two equal parts, and dip each part in iron filings. Make a drawing to illustrate what you have observed.

No matter into how small parts we divide the needle, each fragment will possess poles. Hence, we infer that even the molecules which compose the magnet are magnetic, each having a positive (+) and a negative (—) pole (Fig. 195).

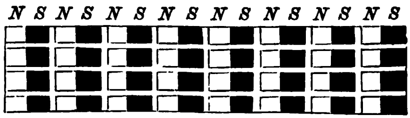

FIG. 195.

If, therefore, the magnet be broken, one face of the fracture must be positive and the other negative. Between the ends, or poles, of the magnet we have the positive pole of one molecule opposed to the negative pole of the adjacent molecule. These equal and opposite poles mutually neutralize each other. (Study again Exp. 179.)

INDUCED MAGNETISM.

Experiment 182.—Bring a piece of soft iron into contact with the pole of a bar magnet, and dip the end of the

soft iron in iron filings. What is the result? Remove the soft iron from the magnet, and note what takes place.

Place upon a box or block of wood the bar magnet, and upon another box the piece of soft iron. Move the soft iron near the bar magnet, but not near enough to touch (Fig. 196).

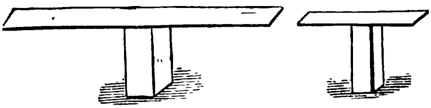

FIG. 196.

Hold a piece of paper with iron filings on it so that the filings may touch both ends of the soft iron. Are they retained by the iron?

Determine the kind of magnetism in the poles of the soft iron, by using a magnetized knitting needle suspended in a paper stirrup. When this is determined, remove the bar magnet.

What is the effect of removing the magnet?

The magnetism which exists temporarily in soft iron when in contact with a magnet, or when brought within the magnetic field, is called Induced Magnetism.

Devise an experiment by which you can ascertain whether magnetism may be induced by induced magnetism.

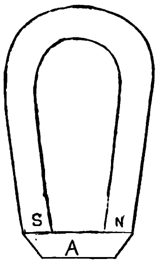

FIG. 197.

The Horseshoe Magnet.—When a magnet is shaped as shown in Fig. 197, it is called a horseshoe magnet. In order to preserve the power of the magnet when not in use, a piece of soft iron *A* is placed over the poles, called a *keeper* or *armature*.

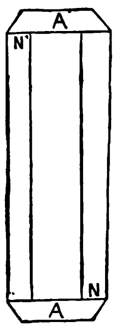

FIG. 198.

Bar magnets are provided with two armatures, which are placed across the poles, as shown in Fig. 198.

Permanent Magnet.—You have noticed that when soft iron (Exp. 182) is removed out of the magnetic field it is no longer a magnet. A piece of steel, as the knitting needle or a knife blade, retains its magnetism when removed out of the magnetic field. Such a magnet is called a *permanent* magnet.*

Experiment 183.—Put a magnetized knitting needle into the fire and heat it red hot. When it has cooled, dip the needle into iron filings. What effect has the heating had upon its magnetism?

THE DIPPING NEEDLE.

Experiment 184.—Take an unmagnetized knitting needle, and with a silk thread suspend the needle from its middle point so that it will exactly balance, or remain in a horizontal position.

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* As soon as ships were constructed of iron plates riveted together, it was found that the hammering of the plates during construction converted them into permanent magnets, the total effect of which on the ship's compass was very large and very irregular; so much so that in one ship the compass varied fifty degrees east in one position of the ship's head, and fifty degrees west in another. It was found by theory, and confirmed by experiment, that the total permanent magnetism could always be resolved into two magnets, one along the ship's length, and the other transverse to the ship. Each of these was separately corrected by a permanent magnet fastened on the deck of the vessel.

After the first few voyages of an iron ship a considerable amount of the magnetism obtained during construction is lost, probably by beating about with the waves, and it is in consequence necessary, while the ship is young, to make a new correction for magnetism after each voyage. Very soon, however, the ship acquires a permanent magnetic condition, after which no further readjustment is needed.—*Cuming.*

Then to keep the thread from slipping, fasten it to the needle with a little melted wax. See that the needle balances perfectly after putting on the wax. Now, taking great care not to shift the thread, magnetize the needle, marking in some way its north pole. When the needle is magnetized, hold it suspended by the thread, and see whether it still exactly balances. If it does not, which end dips below a horizontal line?

Experiment 185.—Magnetize a sewing needle, and suspend it by a silk thread so that it will exactly balance. Place a bar magnet on the table, and put the needle above the neutral part, as shown in Fig 199. Move it half way to the end *N*, and notice its inclination. Put the needle directly over the north pole. Note its inclination. Move the needle back to the neutral line. Now place it half way between the neutral line and the south pole. Next place it directly over the south pole.

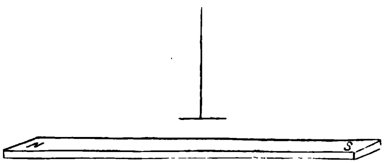

FIG. 199.

Make a sketch of the bar and the position the needle assumes in each of the five places above the bar. In each instance mark the north pole of the needle +, and the south pole —.

If the magnetized knitting needle used in Exp. 183 should be carried to the southern hemisphere, the south pole of the needle would dip below a horizontal line. The knitting needle is a crude form of another instrument called the *dipping needle*, shown in Fig. 200.

How the Dip is measured.—To find the *dip* of any place, the instrument is set so that the vertical plane in which the needle moves is in the magnetic meridian. The *dip* or *inclination* is the angle the needle makes with a horizontal line, read in degrees upon the quadrant scale.

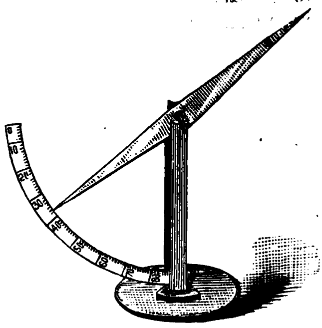

FIG. 200.

The dip varies in different places on the earth. At the magnetic poles the needle is vertical. A line running round the earth and connecting those places where there is no dip is the *magnetic equator*.

Questions.

1. What are the lines of magnetic force ?
2. What is meant by the magnetic field ?
3. What is meant by the polarity of a magnet ?
4. What is the general law of magnetic attraction and repulsion ?
5. What is a natural magnet ?
6. What is the neutral line of a magnet ?
7. Why should an armature be kept in contact with the magnet ?
8. Explain why when a bar magnet is broken two magnets are formed.
9. What is induced magnetism ?
10. What is the difference between permanent magnetism and induced magnetism ?
11. How may the magnetism of a permanent magnet be destroyed ?
12. Two horseshoe magnets of the same size may be so placed that they will form the letter S and cling together. Explain why.
13. Explain why when two horseshoe magnets are placed so that they suggest the figure eight they will in one instance cling together, and in the other instance drop apart.
14. In what direction does the magnetic needle point ?
15. Does it always point in one direction ? Explain.

16. Locate the north magnetic pole.
17. What is a line of no variation ?

FRICTIONAL ELECTRICITY.

Experiment 186.—With a piece of warm silk rub a warm and dry* glass rod or tube. After rubbing, hold the glass rod near some bits of paper or dry elder-pith or any other light body. The bodies are first attracted by the rod and then repelled.

Rub the rod again, and hold it near your hair. Rub a stick of sealing-wax with a piece of warm woollen cloth, and hold the stick near the bits of paper or pith. Are these bodies attracted and repelled by the sealing-wax ?

Electrification.—When certain bodies acquire by friction the property of attracting to themselves bits of pith, paper, or filaments of silk, etc., they are said to be *electrified* or *charged.*

TWO KINDS OF ELECTRIFICATION.

Experiment 187.—Take two pieces of quarter-inch glass tubing fourteen inches long. Seal the ends by holding them in the flame of an alcohol lamp. Make two stirrups of small hair-pins, and attach to each stirrup a fine silk thread, so that the glass rods may be suspended as shown in Fig. 201.

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* All apparatus used in frictional electricity must be warm and thoroughly dry. Care must be taken lest the moisture coming from the breath and the skin dampen the apparatus and cause the experiments to fail. Remember also that dry days are best for experiments in frictional electricity.

Now let one student electrify one glass rod by rubbing it with a piece of silk, and a second student electrify in the same way the other glass rod. When the rods are charged, put them at the same instant in the stirrups, and bring their ends near each other. The rods repel each other. If possible, try in the same manner two sticks of sealing-wax, rubbing these with flannel. Next, let one student electrify again one of the glass rods while a second student electrifies a stick of sealing-wax.

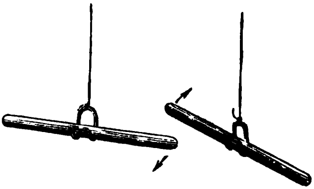

FIG. 201.

When the glass rod is charged, place it in the stirrup, and hold near one end the electrified sealing-wax. The glass and sealing-wax attract each other. This experiment shows that there are two states of electrification; viz., (1) that of glass rubbed with silk, (2) that of sealing-wax rubbed with flannel. The electrification of glass when rubbed with silk is called *positive*, or +; that of sealing-wax or resin when rubbed with flannel is called *negative*, or —.

The electrification represents a condition of matter.

The electrified body acts as if it had upon it a quantity of some invisible, imponderable substance called electricity, which made it attract or repel other bodies.

The terms *positive* and *negative*, used with reference to frictional electricity, are arbitrary ones, used for convenience.

Bodies charged with the same kind of electricity repel each other.

Bodies charged with unlike kinds of electricity attract each other.

PITH-BALL ELECTROSCOPE.

Experiment 188.—Bend a small glass tube, as shown in Fig. 202. Fasten one end in a piece of wood *S*. From the other end suspend by a silk thread *C* a ball of corn-stalk or elder-pith *B*, made as round as possible. Present an electrified body to the pith-ball. The ball will be instantly attracted and then repelled. This apparatus is called an *electroscope*, because it detects the presence of electricity in a body.

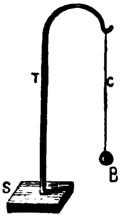

FIG. 202.

SIMULTANEOUS DEVELOPMENT OF POSITIVE AND NEGATIVE ELECTRICITY.

Experiment 189.—Make a flannel cap about three inches long, so that it will fit over the end of a rod of sealing-wax. Attach a silk thread to the cap, as represented in Fig. 203. Turn the cap around on the rod a few times, remove it by the thread, and present the rod to the pith-ball of the electroscope. The ball is first attracted and then repelled; that is, it becomes charged with the same kind of electricity as the rod. Now present the flannel cap, holding it by the silk thread. It attracts the ball. Present the sealing-wax again. The ball is repelled. What kind of electricity was developed on the sealing-wax? What kind on the flannel cap?

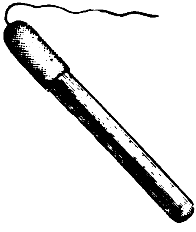
FIG. 203.

When two bodies are rubbed together, positive and negative electrifications are developed, equal in amount. One kind of electrification is never developed without the other.

Experiment 190.—Suspend a pith-ball by a cotton thread, and hold the thread in the hand. Electrify the rod of sealing-wax, and present it to the pith-ball. The ball is continuously attracted to the sealing-wax, and cannot be charged.

The ball does not become charged because the cotton thread conveys or *conducts* the electricity away from the ball to the hand, while from the hand it is conducted by the body to the earth. All bodies do not conduct electricity equally well. *Dry air*, *shellac*, *resins*, *glass*, and *silk* are some of the substances that are poor conductors, or non-conductors.

A body separated from other bodies by a non-conductor, so that when the body is charged the electricity is not conveyed to the earth, is said to be *insulated.*

INDUCTION.

Experiment 191.—Balance a thin strip of wood an inch wide and fifteen inches long on a square bottle, dry

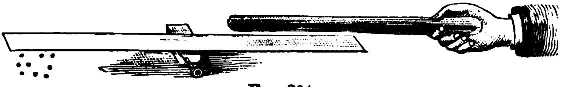

FIG. 204.

and warm. Under one end of the wood place some bits of tissue paper (Fig. 204), and over the other end hold an electrified rod of glass or sealing-wax, taking care not to

touch the wood. The bits of paper are attracted and repelled.

Electrification has been induced in the wood.

The electrification of one body when another electrified body is brought near it, but not touching, is Induction.

Experiment 192.—Balance a small tin pan, warm and dry, upside down on the top of a bottle, as in Fig. 205.

FIG. 205.

Electrify a warm end of sealing-wax with a piece of flannel, and charge the pith-ball of the electroscope so that it is repelled. Now bring the rod of wax near to one side of the tin, and hold the electroscope near the opposite side. What takes place? Gradually bring the electroscope around towards the same side of the tin where the sealing-wax is. The ball is attracted to the tin. With what kind of electricity is the sealing-wax charged? What kind has been induced on that side of the tin next the sealing-wax? What kind on the opposite side of the tin? Can you state the law of induction?

THE ELECTROPHORUS.

Experiment 193.—In an ordinary tin pie-plate melt slowly some resin or sealing-wax. Keep the plate as level as possible, taking care that the contents do not catch fire or boil. You should have the resin in the plate about half an inch thick.

Now cut out a circular piece of tin a little smaller than the resin in the tin plate. Fasten to this tin disk a bottle for a handle.

Place the resin disk on a table, and strike or rub it with a warm piece of flannel, or better, with a piece of cat's fur.

By means of the insulating handle set the tin disk on the resin, and touch the upper side of the tin disk with the finger. Remove the finger, and lift the tin disk from the resin. If the apparatus has been kept warm and dry, you ought to be able to draw a spark from the tin disk by placing your knuckle near it.

Experiment 194.—Fig. 206 represents a sectional view of the electrophorus, as this instrument is called. *D* is the sealing-wax or resin, with the tin plate *T* on the under side; *C* is the tin disk to which is fastened the handle *H*. When we rub *D* with a cat's fur or flannel, we develop negative electricity on its upper surface. This induces + electricity on the upper, or nearer, side of the tin *T*, while the – electricity is repelled to the under, or farther, side, as in Exp. 192 it was repelled to the farther side of the tin. This – electricity is neutralized by its contact with the earth, and *T* remains charged with + electricity. The tin disk *C* will not touch *D* at more than one or two points. There will be a thin layer of air between.

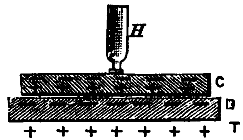

FIG. 206.

What kind of electricity is therefore induced on the lower side of *C*? When you touch the upper side with the finger, what kind passes off to the earth? When *C* is finally lifted from *D*, with what kind of electricity is *C* charged?

To electrify a conductor by means of this instrument, obtain a charge of + electricity on the tin disk, as described, and then present the tin disk to the body to be electrified. A spark will pass from the one to the other. Repeat the operation several times until the body is electrified with the charge desired.

DISTRIBUTION.

Experiment 195.—Make a cone-shaped muslin bag, and sew the edge to a wire ring, as in Fig. 207. Let the ends of the wire forming the ring be bent downwards, so as to hold the ring upright in the cork of a bottle. Fasten two silk threads to the apex of the bag in such a way that the bag can be drawn inside out.

FIG. 207.

By means of shellac, fasten a copper cent to the side and at the end of a glass rod about six inches long. This little instrument is called a *proof-plane*, and is used to test charged bodies.

Electrify the muslin bag by means of an electrophorus, and then touch it on the outside with the proof-plane. Upon holding the proof-plane towards the electroscope, you will find that it has received a charge of electricity from the bag. Touch the proof-plane in order to discharge it, and then test the inside of the bag in the

same way. Is there any electricity on the inside of the bag?

By means of the silk thread, turn the bag inside out, and test both inside and outside as before. Where do you find the electricity?

When a body is charged with frictional electricity the charge is confined to the outside of the body. If, however, an insulated, electrified body is held within a metallic vessel, electricity will be induced on the inner surface of the vessel.

POTENTIAL.

When a body at a higher temperature comes in contact with a body at a lower temperature, the former loses some of its heat to the latter, and this continues until both bodies are of the same temperature. Just as bodies may be in different states in regard to heat, so we have learned bodies are in different states of electrification. That which corresponds to temperature in heat is called *potential* in electricity. In order that there may be a flow of electricity from one conductor to another, the first conductor must possess a higher potential than the second.

In electricity the earth is taken as the standard. A body positively electrified is at a higher potential than the earth. A body negatively electrified is at a lower potential than the earth. A body that is neutral is at the same potential as the earth.

ELECTRICAL MACHINES.

Electrical machines are mechanical contrivances for utilizing the principle of the electrophorus, and so obtaining an increased charge of electricity. Fig. 208 shows an

electrical machine of the most improved form, called the Toepler-Holtz machine.

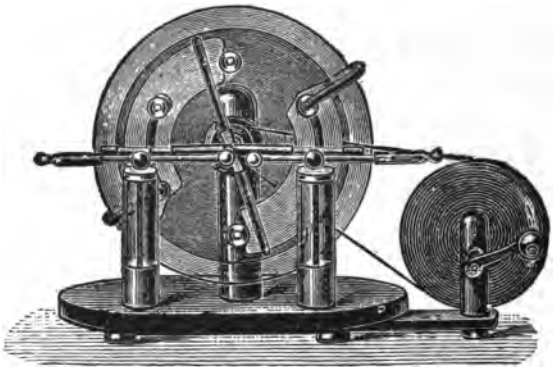

FIG. 208.

CONDENSERS.

The Leyden Jar.—Procure a glass jar *L* (Fig. 209), or a large-mouthed bottle six or seven inches high. Using a weak solution of gum-arabic, cover both the outside and the inside with tin-foil to within one-third of the height from the top. Fasten circular pieces of tin-foil to the bottom of the jar, inside and outside, taking care that each joins the coating on the sides. Varnish the strip of glass that has been left exposed around the top of the jar. Through a varnished wooden cover pass a brass wire five inches long, and from its lower end suspend a brass chain long enough to reach the bottom of the jar. Make a hole in a good-sized bullet, and press it on the upper end of the wire.

FIG. 209.

Through the cork of a slim bottle *H* (Fig. 209), pass an-

other wire, bent as shown in the figure. Fasten a bullet on each end. This piece of apparatus is called a *discharger.*

Experiment 196.—Set the Leyden jar on the table, or, better, hold it in the hand, and electrify the ball many times with the electrophorus,* in order to charge the jar, observing the spark. Now touch the tin-foil with one ball of the discharger, and gradually bring the other ball nearer the knob of the jar. How does the spark you obtain compare with a spark from the electrophorus?

Evidently the numerous small charges of electricity that you put into the jar were held there, and united to form one greater discharge.

An apparatus such as the Leyden jar, which collects successive charges of electricity and confines them on a smaller surface than they would ordinarily spread over, is called a *condenser.*

When the tin-foil within the jar became charged with + electricity, what kind of electricity was induced on the inner surface of the tin-foil without the jar? What kind passed from the outer surface of the tin-foil through the hand and body to the earth? Explain the further action of the jar and its discharge.

EFFECTS OF POINTS.

Experiment 197.—File one end of a piece of wire about three inches long to a point, and twist the other end

* A frictional electrical machine, if the school has one, will charge the jar more quickly, though such a machine is not essential.

about the knob of the Leyden jar. Try to charge the jar with the electrophorus, as in the previous experiment. After a number of charges, can you obtain any discharge ?

Again, remove the wire and charge the jar. Now, holding the wire in the hand, with the point directed to the knob of the jar, but not touching it, try to discharge the jar. Do you obtain any spark ? In the first case, the molecules of air coming in contact with the pointed wire, each molecule in turn conveyed away the + electricity from the jar, until the jar was discharged. In the second case, the knob of the jar inducing − electricity on the point of the wire, this − electricity was conveyed by the molecules of air to the knob, and so discharged the jar.

From a pointed wire attached to the charged condenser of an electrical machine the molecules of air act in this way fast enough to blow out a lighted candle.

Lightning-rods.—The phenomenon known as lightning is only a discharge of frictional electricity. Knowing this, can you explain how lightning-rods protect a house from being struck ? Which has the higher potential, the thunder-clouds or the house ? Does the action of lightning-rods correspond to the first or to the second of the experiments you have just tried with the pointed wire and the Leyden jar ?

Questions.

1. What is the general law of electrical attraction and repulsion ?
2. How can you show that positive and negative electrifications are produced simultaneously ?
3. What are conductors ? What, non-conductors ? What other name is given to non-conductors ?
4. What is an electroscope ?

5. Make a diagram of an electrophorus, and describe the method of charging it.

6. Explain electrical induction.

7. Describe the construction of the Leyden jar.

8. How is a Leyden jar charged ? How discharged ?

9. Explain fully what occurs when the jar is charged and discharged.

10. Why can a stronger spark be obtained from the Leyden jar than from the machine by which it is charged ?

11. A student, standing upon the floor, once tried to light the gas with a charged Leyden jar. He turned on the gas, and touched the tip of the gas jet with the knob of the jar, but instead of lighting the gas, he received a shock of electricity. Why ? What should he have done ?

12. Why are lightning-rods pointed ?

Exps.

VOLTAIC ELECTRICITY.

Experiment 198.—Cut out a piece of sheet zinc four inches long and one and a half inches wide. Place this in a tumbler of dilute sulphuric acid.* Notice the action the acid has upon the zinc. Bubbles of gas collect on the zinc and rise to the surface of the liquid. These bubbles are hydrogen gas.

Experiment 199.—After the zinc has remained in acid a few seconds, take it out, and with an old tooth-brush or a piece of cloth rub mercury over both surfaces of the zinc. Take only a tiny drop of mercury for this. When you rub the mercury on the zinc, lay the zinc on a perfectly flat surface, and be very careful not to bend it.

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* The dilution of sulphuric acid needed in this and other experiments is twenty parts of water to one part of sulphuric acid. Always pour the sulphuric acid into the water. Never pour the water upon the sulphuric acid. Be careful not to get any of the pure or dilute acid upon your hands or clothes.

Notice that the mercury clings to the zinc and gives the surface a bright appearance. Coating zinc with mercury in this way is called *amalgamating* the zinc.

Now put the amalgamated zinc in the dilute sulphuric acid, and see whether the acid has the same effect upon the zinc as it had before it was amalgamated.

If the zinc is thoroughly amalgamated, no bubbles will rise.

Experiment 200.—Cut out a piece of sheet copper four inches long and one and a half inches wide (the size of the zinc in Exp. 198). See that the copper has no solder or tin upon it. Put this piece of copper in the tumbler of dilute acid. Has the acid any action upon the copper? Do you see any bubbles collecting on the copper and rising to the surface of the acid?

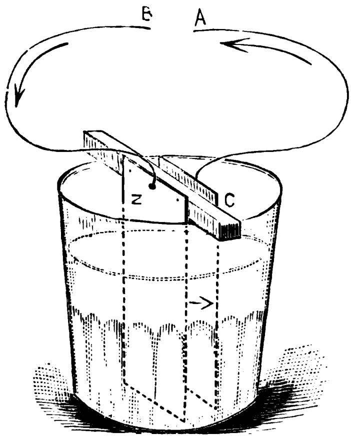

FIG. 210.

Experiment 201.—Procure a piece of pine about four inches long and one inch square. Tack the piece of copper used in Exp. 200 on one side of the stick, and the piece of zinc used in Exp. 198 on the other. Take care that the tacks from either side do not touch each other in the wood. Take two pieces of copper wire, each about two feet long.

Twist the end of each once or twice around a tack, and drive one tack through the zinc into the wood, and the other tack through the copper. One piece of wire is now in contact with the zinc, and one in contact with the copper. Put the two strips of metal into the tumbler of acid, as shown in Fig. 210. Connect the ends of the wires *A* and *B*. Notice that hydrogen bubbles collect on the copper strip and rise to the surface of the acid. Disconnect the wires. Do the bubbles continue to rise? Connect the wires again. Do bubbles rise?

A Current of Electricity and its Direction.—When the wires *A* and *B* in the previous experiment (201) were connected, a *current* of *electricity* * was set up.

The current of electricity is said to flow from the zinc to the copper through the acid, and along the wire from the copper strip to the wire connected with the zinc.

If you connect the wires *A* and *B* (Exp. 201), and let the current of electricity flow for a few hours, you will find that the zinc wastes away, or is used up, by chemical action.

After you have performed Exp. 203, connect *A* and *B* for several hours.

THE VOLTAIC CELL.

The Terms, Cell, Battery, and Poles.—The combination of zinc, copper, and dilute acid (Fig. 210) is called a *voltaic cell.* The two metals are called the *elements,* and the acidulated water the *exciting fluid.* Several cells constitute a *battery,* though a single cell is often called a battery.

* What electricity itself really is, is not known. We know how to produce it by certain methods, and also what can be done with it when it has been produced.

The extremities of the wire *A* and *B* (Fig. 210) are called *poles*, or *electrodes*.

The current of electricity in such a cell as we have been using flows from the zinc, or positive element, where the chemical action takes place, through the liquid, to the copper, or negative element, thence through the connected wires to the zinc element. The end of the wire *A* from the copper element will be a *positive* electrode (+), and the end of the wire leading to the zinc element will be a *negative* electrode (—), when the current is flowing.

CONDUCTORS.

Experiment 202.—Connect the wires of the cell (Fig. 210) so that a current of electricity may flow. Now place between the electrodes a piece of wood. Does the current continue to flow? Try pasteboard, glass, a piece of gutta percha, a piece of silk or cotton cloth, a piece of wax.

Does a current flow through the wires?

Interpose a silver coin between the wires. Does the current flow? Try a piece of iron; a piece of brass.

Cut a little trough in a piece of wood, put a drop of mercury in this, and place the ends of the wire in the opposite ends of the trough of mercury. Does the current flow?

Those substances through which electricity passes easily are called good Conductors. Substances through which electricity passes with great difficulty are called Non-Conductors, or Insulators.

Make a list of the good conductors and a list of the non-conductors used in Exp. 202.

COMMON VOLTAIC CELLS.

Polarization.—In the cell we have been using you noticed that, though bubbles of hydrogen streamed up from the copper plate, there was always a collection of hydrogen bubbles on the surface of the plate. This hydrogen acts in the first place as a *non-conductor* to the electricity, and so weakens the current; in the second place, the hydrogen forms a positive element to the copper, and so tends to set up a current with it in an opposite direction to the current set up between the zinc and the copper.

The formation of a film of hydrogen on the copper plate, or any other action which tends to set up a current in an opposite direction, is called Polarization.

The Two Classes of Cells.—In order to lessen the polarization in a cell, various forms of cells have been devised. These may be divided into two general classes: (1) those which have in each cell one fluid; (2) those which have in each cell two fluids.

Smee's Cell.—A Smee's cell (Fig. 211) consists of two zinc plates, between which is a silver plate. The surface of this silver plate is roughened by being covered over with finely divided platinum. The bubbles of hydrogen are discharged more easily from the points of this roughened surface than if the silver plate were smooth. The fluid is dilute sulphuric acid.

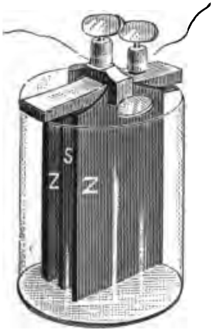

FIG. 211.

FIG. 212.

The Bichromate Cell.—One form of the bichromate cell is shown in Fig. 212. It consists of a bottle-shaped glass vessel, containing a zinc plate *Z* attached to a sliding brass rod, by which it may be drawn up out of the liquid when a current is not needed. Two carbon plates *C C* are attached to the vulcanite cover. The exciting liquid is a solution of potassium bichromate in sulphuric acid. (For the exact proportions, see Appendix, § 6.) This cell gives a strong current for a short time.

The Gravity Cell.—The gravity cell (Fig. 213) has a copper plate placed at the bottom of a glass vessel and the zinc plate near the top. The exciting liquid is a solution of copper sulphate (blue vitriol) in water. This cell is largely used on telegraphic lines.

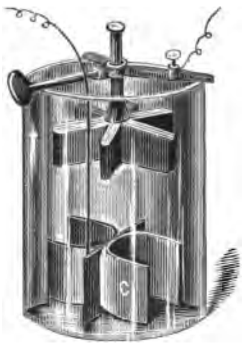

FIG. 213.

The Le Clanché Cell.—This cell consists of a zinc rod *Z*, and a carbon plate *C*, which has on each side a prism of binoxide of manganese *B*, *B* (Fig. 214). The exciting fluid is a solution of ammonium chloride (sal ammoniac) in water. The prisms of binoxide of manganese prevent polarization by uniting with the hydrogen bubbles. This cell is used where a current is needed for a brief interval of time, as in working telephones and electric bells.

FIG. 214.

The Bunsen's Cell.—The Bunsen's cell (Fig. 215) is a two-fluid battery. The outer glass vessel contains dilute sulphuric acid. In this acid is placed a zinc cylinder *Z*, having a slot cut in it lengthwise. Inside the zinc is put a porous, unglazed, earthenware cup *E*, containing strong nitric acid, in which is immersed a rod of carbon *C*.

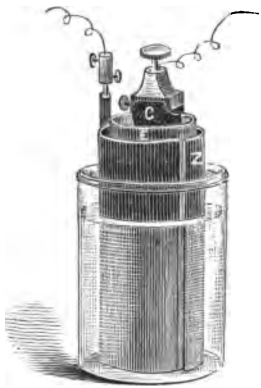

Fig. 215.

THE ELECTRO-MAGNET.

Experiment 203.—Wind around a piece of soft iron a quarter of an inch in diameter (a carriage bolt will answer) eighteen feet of No. 20 insulated copper wire.* This will make four turns of wire around the bolt. Connect the ends of the wire with the plates of the cell used in Exp. 202, or any other cell that you may have. Now put the ends of the iron rod into iron filings. The iron filings cling to the ends of the rod, showing that the rod has acquired magnetic properties. Such a magnet is called an *electro-magnet*. The coil of wire is called a *helix*, and the iron in the helix is called its *core*. Disconnect one wire from the battery. The iron filings fall. Connect the wire again with the battery. Will iron filings now cling to the rod?

The rod becomes an electro-magnet when the current flows through the helix, and ceases to be a magnet when

* Wire covered with any of the non-conductors, cotton, silk, or india rubber, is called *insulated* wire.

the current is not allowed to flow. Connecting the wires so that the electricity will flow through the helix, and then separating them so as to stop the flow, is called *making* and *breaking*, or *closing* and *opening*, the circuit.

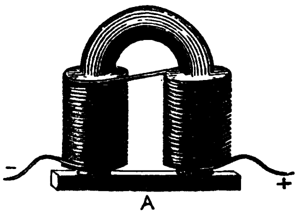

FIG. 216.

An electro-magnet is a bar of soft iron, generally in the shape of a horseshoe (Fig. 216), round which a coil of insulated copper wire is wound. A current of electricity is passed through the coil. The bar *A* is the armature.

Electro-magnets are much more powerful than ordinary permanent magnets, and are used to magnetize bars of steel.

THE TELEGRAPH.

Principle Involved and Instruments Used.—You have now learned how an electro-magnet may be produced. The electric telegraph works by alternately making and unmaking an electro-magnet at a distance. For telegraphing, it is necessary to have a battery to generate the currents, a wire to connect the two places, a key, and a sounder.

Two lines were formerly employed in telegraphing ; one being used for the current to pass to the receiving station, and the other for the current to return to the battery. Now only one wire is used. The zinc plate at one end of the line and the copper plate at the other end are each connected with a large plate of metal buried in the earth. The earth takes the place of a return wire.

The Key.—The telegraph key is shown in Fig. 217. The instrument is made of brass, except that the knob *H* of the lever and the knob *S* of the switch are of vulcanite. The

switch is closed in Fig. 217, and allows the current to pass through the key and along the main wire.

The wires are wound around the posts *W W'*. When a

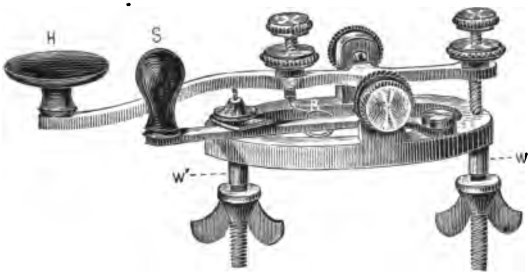

FIG. 217.

message is to be sent, the switch is first thrown open. Then by pressing down on the knob *H* of the lever, a little point under the lever touches the end of the post *W'*, and the circuit is closed. When the pressure is removed, the spring *B* raises the lever, and the circuit is broken.

The Sounder.—When the circuit is closed, the armature *A* of the *sounder* (Fig. 218) is drawn down by the electro-magnet *E*; and when the circuit is broken, *E* is no longer an electro-magnet, and the armature *A* is thrown up a little way by a spring under the lever *L*.

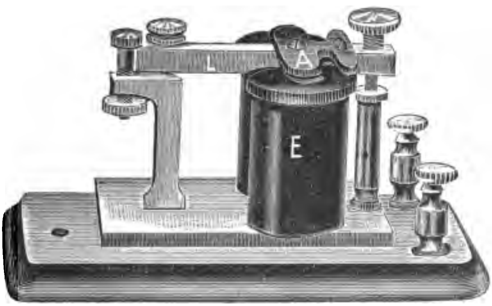

FIG. 218.

As often as the operator presses down on the lever of

his key and allows it to spring back, the same action takes place in the sounder, and a click is heard.

The operator receiving a message reads the letters by the duration, number, and arrangement of the clicks.

Formerly messages were printed by the receiving instrument, or sounder. A point attached to the armature lever pressed down upon paper, and made dots and dashes. Because of this, the telegraphic alphabet is represented by printed dots and dashes.

TELEGRAPHIC ALPHABET.

A	B	C	D	E	F
. —	— . . .	. . .	— . .	.	. — .
G	H	I	J	K	L
— — .	. . . .	. .	— . — .	— . —	——
M	N	O	P	Q	R
— —	— .	. .	. . . . .	. . — .	. . .
S	T	U	V	W	X
. . .	—	. . —	. . . —	. — —	. — . .
Y	Z	&	,	?	.
. . . .	. . . .	. . . .	. — . —	— . . — .	. . — — . .

FIGURES.

1	2	3	4	5	6
. — — .	. . — . .	. . . — .	. . . . —	— — —	. . . . . .
	7	8	9	0	
	— — . .	—	— . . —	——	

At most offices, messages are now read by the sound of the clicks.

The Relay.—With a given battery, if the current is to be sent over a very long wire it will be too weak to draw the armature of the sounder down. To remedy this a relay is introduced. The relay has a helix of very fine wire, and when the weak current reaches it, the electro-magnet attracts its armature, and thus brings into use a local battery which works the sounder. Fig. 219 shows the arrangement of relays, sounders, and keys.

In Fig. 219 the switch *A* is open at Philadelphia. Press the key at Philadelphia. What effect will this have upon

the relay at Philadelphia and the relay at New York? When the armature E of the relay at New York is drawn to the magnet, what takes place at C? How does this operate the sounder G? How do the relay and the sounder

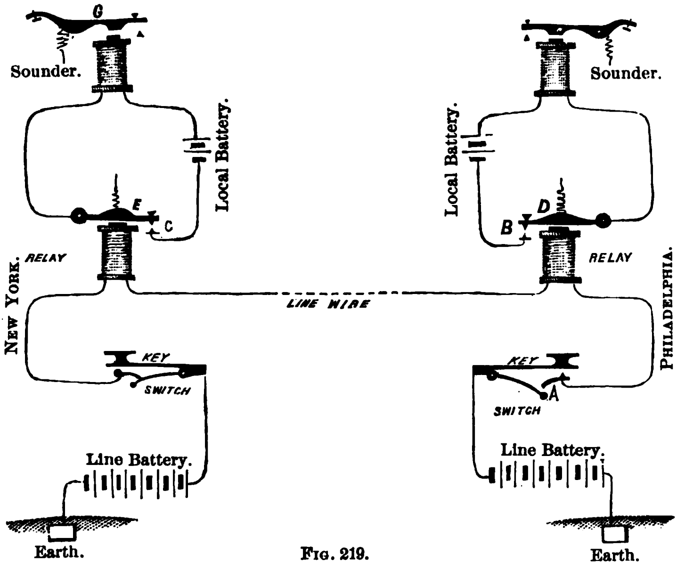

FIG. 219.

at Philadelphia work at the same time? Does the direction in which the message is sent make any difference in the working of the instruments?

THE ELECTRIC BELL.

Explanation.—One form of the electric bell is indicated in Fig. 220. The hammer B is attached to a piece of soft iron D, which acts as an armature of the electro-magnet C. To the armature D is attached a spring O which brings it back to the position shown in Fig. 220, after it has been attracted by the electro-magnet. E is a spring so adjusted that when the armature is drawn to the electro-

magnet there is no electrical connection between E and D. As soon as the circuit is closed, the current passes through the insulated wire N, which is wound around the soft iron, then through the wire M, up the spring O and the armature D, to the point where the spring E touches the armature, down the spring E to the binding-post P, and thence back to the battery. As soon as the current completes its circuit, C becomes an electro-magnet, and attracts the armature D, causing the clapper to strike the bell. The instant the armature is drawn to the electro-magnet, contact is broken with the spring E, the electro-magnet is unmade, and the spring O carries the armature back to the spring E, remaking contact with the battery. In this way a vibrating motion of the clapper is set up, and the bell rings. The battery usually consists of two or three Le Clanché cells, and contact is made at a distance by means of a *push-button*.

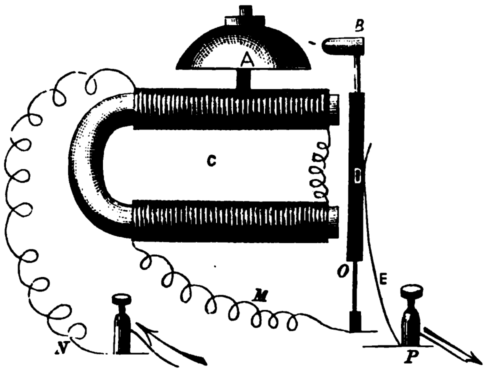

FIG. 220.

Examine any electric bell you may have, and show how the current passes through the bell from one binding-post to the other.

EFFECT OF THE CURRENT UPON A MAGNETIC NEEDLE.

Experiment 204.—File a knitting needle in two and magnetize both halves at the same time. Mark the north

end of one half, and put it aside for use in Exp. 206 (the astatic needle).

Suspend the other half by an untwisted silk thread.* When the needle has come to rest, hold above the needle, and as near as possible without touching it, an insulated copper wire through which a current of electricity is passing. What is the effect upon the needle?

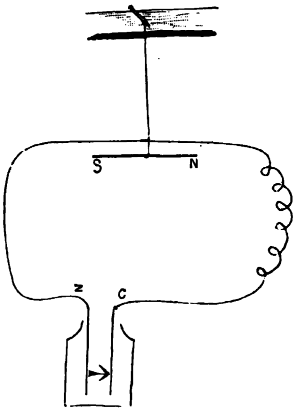

FIG. 221.

Arrange the cell used so that the current shall flow from south to north above the needle. Which way is the north end of the needle now deflected?

Hold the wire so that the current shall flow from south to north below the needle. Which way is the north end of the needle now deflected?

Turn cell about so that the current in the wire shall flow from north to south, and hold the wire above the needle. Which way is the north end of the needle deflected?

Hold the wire below the needle. Which way is the north end of the needle now deflected?

Ampère's Rule.—Ampère formulated a rule for readily determining the deflection of a magnetic needle, due to an electric current passing through a wire parallel to the needle.

* For an untwisted silk thread unravel the end of a piece of ribbon.

Let the observer imagine himself swimming in the direction the current moves, and facing the needle, then the north end of the needle will always be deflected to his left hand.

Experiment 205.—Suspend the same needle used in the previous experiment. Bend insulated copper wire into the form of an oblong, place it near the needle, as shown in Fig. 222. Pass a current through the wire from the same cell used in the preceding experiment. Explain why the needle is deflected more than when one wire was used, as in Exp. 204. Make several turns of wire, as shown in Fig. 223, and see if the needle is deflected more than with one turn.

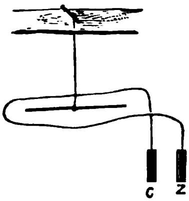

FIG. 222.

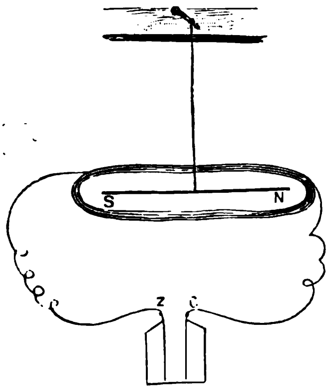

FIG. 223.

THE ASTATIC NEEDLE.

Experiment 206.—Twist copper wire about each of the two halves of the knitting needle magnetized in Exp. 204 so that the north pole of one half shall be above the south pole of the other. Suspend the pair by an untwisted silk thread so that they will move in a horizontal plane (Fig. 224). Does the pair point as strongly in one direction as a single needle? Why?

A combination of two magnetic needles with their poles so arranged that the earth's magnetism has no directive influence upon them is called an Astatic Needle.*

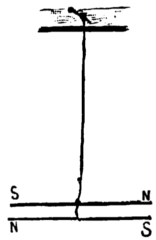

Fig. 224.

Pass a current of electricity around the astatic needle, as shown in Fig. 225. Can you explain why it is deflected more than a single needle was with one turn of wire in Exp. 204 ?

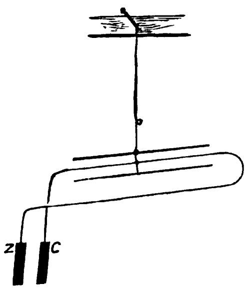

Fig. 225.

THE GALVANOMETER.

Its Use.—We have learned that when a wire through which a current is passing is placed above a magnetic needle, the needle is deflected (Exp. 204) ; that when several turns of wire are made about the needle, the needle is still more deflected (Exp. 205).

If, then, we wish to ascertain whether a current is passing through a wire, we can introduce into the circuit several turns of wire wound about a magnetic needle, and a deflection of this needle will indicate the presence of a current in the wire.

A *galvanometer* is constructed upon this principle.

It can be used not only to detect the presence of a current, but also to show its direction, and roughly to indicate its intensity.

* It is very difficult to make a perfect astatic pair, for the two needles must be of equal length and of exactly the same magnetic strength. They must be parallel and their axes must lie in the same vertical plane.

How to construct a Galvanometer.—Construct a galvanometer by winding about a wooden frame six inches long, one and three quarter inches wide, seven-eighths of an inch deep, about twenty-eight turns of insulated copper wire No. 20 (fourteen turns on each side of the magnetic needle).

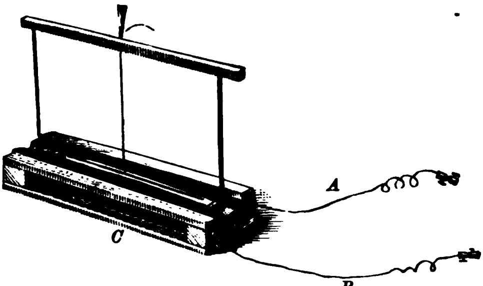

Fig. 226.

Suspend by an untwisted silk thread the magnetic needle used in Exp. 204, so that it may move in a horizontal plane between the upper and lower winding of the wire.

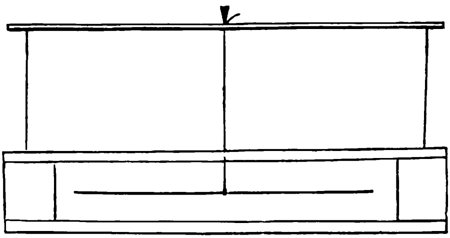
Fig. 227.

Put a pin at *C*, to prevent the needle from turning more than half way. Fig. 226 is a sketch of the instrument when completed. Fig. 227 gives a side plan of the wooden frame, and Fig. 228 a top or bottom plan. No iron must enter into the construction. Next make on paper a graduated circle two inches in diameter, which is to be placed under the galvanometer, so that the centre

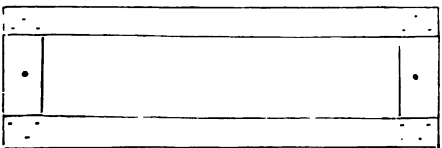
Fig. 228.

of the circle may lie directly below the point where the needle is suspended. In using this galvanometer it must be set so that the sides shall be parallel with the needle. Both will point in the direction of the magnetic meridian.

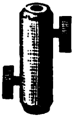

FIG. 229.

To prevent a disturbance of the galvanometer when set, place a heavy piece of wood over the wires *A* and *B* (Fig. 226), which should extend out a foot from the frame. Connectors, or binding screws (Fig. 229), are fastened to *A* and *B*. (For home-made connectors, see Appendix, § 7.)

EXTERNAL RESISTANCE.

Experiment 207.—Take one hundred feet of No. 16 insulated copper wire, and make a coil about six inches in diameter.

Make a second coil of one hundred feet of insulated copper wire No. 30; a third coil of fifty feet of insulated copper wire No. 30; a fourth coil of fifty feet of insulated German silver wire No. 30.

Introduce into the circuit of the galvanometer a gravity cell, and note the deflection of the needle.

Now with the same cell introduce into the circuit one hundred feet of No. 16 copper wire. Note exactly how much the needle is deflected. Is it deflected more or less than it was without the wire?

Introduce into the circuit the one hundred feet of No. 30 copper wire. Note again the deflection of the needle. Is it deflected more or less than when the same length of No. 16 copper wire was in the circuit?

Introduce into the circuit the fifty feet of No. 30

copper wire. Notice the deflection of the needle. How does the amount of deflection compare with that when one hundred feet of the same kind of wire was in the circuit?

Lastly, introduce into the circuit the fifty feet of No. 30 German silver wire. Note the deflection of the needle. How does the amount of deflection compare with that when fifty feet of copper wire of the same size was used?

We found, in comparing the deflection of the needle, when there was no coil in circuit with its deflection when any of the coils was in circuit, that the current acted as if it met with a certain amount of opposition in the wire. This apparent opposition to the flow of the current is called *resistance.*

Which has the more resistance, one hundred feet of No. 16 copper wire or one hundred feet of No. 30 copper wire? Since the material is the same and the length the same, to what is the difference due?

Which has the greater resistance, one hundred feet of No. 30 copper wire or fifty feet of No. 30 copper wire? To what is the difference in this instance due?

Which has the greater resistance, fifty feet of No. 30 copper wire or fifty feet of No. 30 German silver wire? To what is the difference in this instance due?

The resistance of a conductor increases with its length, and decreases as its cross-section increases.

The nature of the material has also to be taken into account in estimating resistance.

Resistance is measured in Ohms.*

An ohm is the resistance of two hundred and fifty feet of No. 16 copper wire or ten feet of No. 30 copper wire.

INTERNAL RESISTANCE.

Experiment 208.—Connect a gravity battery, in which the plates are as far apart as possible, with the galvanometer, and note the deflection of the needle. Then bring the plates as near together as possible, and note the deflection of the needle. In which instance did the galvanometer show the greater strength of current?

The resistance which the liquid offers to the passage of the current is called Internal Resistance.

ELECTRO-MOTIVE FORCE.

Experiment 209.—Cut out a copper and a zinc plate four and three-quarters by three and one-quarter inches. Amalgamate the zinc. Nail each plate to a strip of wood, fastening at the same time a copper wire to each. Now put them into a jar of dilute sulphuric acid. The dilute acid should come almost to the top of the plates. Connect the wires from the plates with the galvanometer, and note how much the needle is deflected.

Remove the zinc plate, and put in its place a plate of sheet lead of the same size. Connect the wires from each plate with the galvanometers, and note how much it is deflected.

With which pair, copper and zinc, or copper and lead, was the needle deflected the more?

---

* The *ohm* is named from a German investigator, G. S. Ohm, who first stated the laws which determine the strength of currents.

If possible, try a carbon plate with the zinc plate, and compare the deflection with the deflection of the needle when the zinc and copper plates were in the acid.

Electro-motive Force and its Unit of Measure.—To account for a greater deflection of the needle when zinc and copper are used than when lead and copper, we say that a cell with zinc and copper plates has a greater *electro-motive force* (written E. M. F.) than a cell with lead and copper plates.

A cell with zinc and carbon plates has a greater E. M. F. than a cell with zinc and copper plates.

The unit of measurement of electro-motive force is called a Volt.*

The E. M. F. of a current from one gravity cell is about one volt. A Grenet cell has an E. M. F. of about two volts ; a Le Clanché cell has an E. M. F. of about one and a half volts.

STRENGTH OF CURRENT.

Experiment 210.—Construct another galvanometer according to directions given (p. 252), but instead of using No. 20 insulated copper wire use No. 12 insulated copper wire, and wind but two turns around the frame on each side of the needle.

Procure an empty copper cartridge-shell one inch long and about half an inch in diameter, and twist tightly around it a copper wire. Cut a strip of zinc one-eighth of

* Volt from Volta, an Italian scientist, who in the very first part of this century made important discoveries in Electricity.

Galvani was another Italian investigator, who made some important discoveries a few years previous to those made by Volta.

an inch wide and one and one-quarter inches long. Fasten a copper wire to one end of the zinc. Next bore a small hole through the zinc near the wire and three-quarters of an inch from the end, so that a piece of match may be put through the hole. Fill the copper shell with dilute sulphuric acid, put in the strip of zinc, and push the piece of match through the hole so that the zinc will not touch the bottom of the shell (Fig. 230).

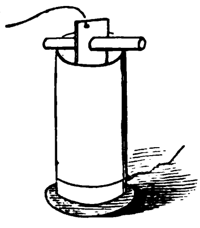

FIG. 230.

Connect the wire from this little cell with the galvanometer made of No. 20 copper wire, and note carefully the deflection. Now connect with the same galvanometer the cell used in Exp. 209, having its zinc and copper plates four and three-quarters by three and one-quarter inches. Note carefully the deflection of the needle. The deflection is the same in each case.

Connect the wire from the small cartridge battery with the galvanometer made of No. 12 wire, and note carefully the amount the needle is deflected.

Now connect the cell having the large plates with this galvanometer, and note the deflection of the needle.

With the large cell, you noticed that there was a much greater deflection than with the little cell. This shows that the larger cell, though its E. M. F. is the same as that of the smaller cell, is able to yield a much greater quantity of electricity.

When, however, these cells were connected with the galvanometer made of much smaller wire (No. 20), the needle was deflected the same amount by each, because only a

small quantity of electricity could pass through the fine wire galvanometer, on account of its resistance, and the smaller cell yielded that quantity as well as the larger one.

THE DIFFERENCE BETWEEN STRENGTH OF THE CURRENT AND ELECTRO-MOTIVE FORCE.

Upon what Electro-motive Force depends.—The electro-motive force of the large cell used in Exp. 210 was no greater than the electro-motive force of the small cell. The electro-motive force set up by the two elements of a battery depends upon what is termed their difference of potential, and is wholly independent of the size of the plates.

Although the electro-motive force of the large cell was the same as that of the small cell, there was considerable difference in the quantity of electricity generated by each.

The quantity of electricity which passes through a conductor in a given time determines the *strength of the current.*

The Ampère.—The measure of *strength of current* is called an *ampère.* It is the strength of current maintained by an E. M. F. of one volt, through a resistance of one ohm.

Ohm's Law.—The relation existing between the strength of a current, the electro-motive force, and the resistance was first stated by Ohm in the following law :

The strength of a current varies directly as the electro-motive force, and inversely as the resistance.

This law is expressed by the formula :

$$C = \frac{E}{R}$$

Where C is the strength of current in *ampères,* E is the electro-motive force in *volts,* and R is the entire resistance in the circuit in *ohms.*

If we wish to distinguish between the external and the internal resistance, the formula may be written :

$$C = \frac{E}{R + r}$$

in which *R* represents external, and *r* internal, resistance.

Application of the Formula.—Suppose the E. M. F. of a cell is two volts, the external resistance *R* three ohms, and the internal resistance *r* one ohm, what is the strength of the current?

Solution :

1 $$C = \frac{E}{R + r} = \frac{2 \text{ volts}}{3 \text{ ohms} + 1 \text{ ohm}} = \frac{2}{4} = \frac{1}{2} \text{ ampère.}$$

2 When the E. M. F. is eight volts,* and the resistance is three ohms, what is the strength of current?

3 With an E. M. F. of fifteen volts, and a resistance of twenty-five ohms, what is the strength of current?

Find the resistance in a circuit when an E. M. F. of fifteen volts gives a current of one and a half ampères.

5 What is the E. M. F. when the current strength is seven ampères, and the resistance eight ohms?

Arrangement of Cells.—The cells of a battery may be arranged in a variety of ways. The copper or carbon of one cell may be joined to the zinc of the next, and so on, as shown in Fig. 231.

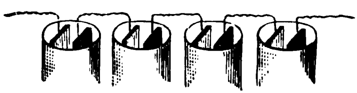

FIG. 231.

This is called coupling, or arranging the cells *in series.* When four cells are

* As a single cell can give at most but two and a half volts, let it be understood, for the purpose of the problems, that the E. M. F. comes from several cells.

joined in series, the total current generated by the battery passes through the liquid of each cell, or, in other words, through a liquid conductor four times as long as the liquid conductor of one cell. This increases the internal resistance fourfold. The E. M. F. of the battery, however, is four times as great as that of one cell. So that if it is desired to send a current through a long and small wire—in other words, if the external resistance be great as compared with the internal resistance—the cells should be coupled in series.

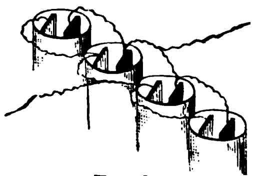

FIG. 232.

Instead of joining copper to zinc, or in series, all the copper plates may be joined, and all the zinc plates be joined, as in Fig. 232.

This is called arranging the cells *parallel*, or *in multiple arc*, or *abreast*.

When cells are arranged parallel (Fig. 232) the current divides itself between the cells, and the internal resistance of the four cells is one-quarter that of a single cell, because the liquid conductor of the current is four times as wide as that of one cell.

The E. M. F. of cells joined parallel is only equal to that of one cell.

If the internal resistance be great as compared with the external resistance, the cells should be joined *parallel*.

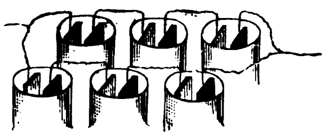

FIG. 233.

The strongest current is obtained when the internal resistance of the battery is equal to that of the external resistance of the circuit. To secure this it often becomes necessary to arrange the cells partly *in series* and partly *parallel*, as shown in Fig. 233.

Suppose, for example, that we have eight cells, each hav-

ing an E. M. F. of two volts, and a resistance of eight ohms, and that the external circuit has a resistance of sixteen ohms. How shall the cells be arranged to produce the strongest current?

First, let us arrange the cells in series, and then calculate the strength of the current by Ohm's law.

$$E = 2 \text{ volts} \times 8 \text{ (number of cells)} = 16 \text{ volts.}$$

R = 8 ohms (internal resistance of each cell) × 8 (number of cells) = 64 ohms + 16 ohms (resistance of external circuit) = 80 ohms.

Then as

$$C = \frac{E}{R}, \text{ we have } \frac{16}{80} = \frac{1}{5} \text{ ampère, the strength of the current.}$$

Second, arrange the cells parallel.

$$E = 2 \text{ volts.}$$

R = 1 ohm (internal resistance being $\frac{1}{8}$ of what it is in one cell) + 16 ohms (resistance of external circuit) = 17 ohms.

Then as

$$C = \frac{E}{R}, \text{ we have } \frac{2}{17} \text{ ampère, the strength of the current.}$$

Third, arrange the cells in two rows, four cells being in series in each row, and the two rows being joined parallel.

$$E = 2 \text{ volts} \times 4 = 8 \text{ volts.}$$

R = 8 ohms (internal resistance of each cell) × 4 (number of cells) = 32 ohms. 32 ohms ÷ 2 (the two rows being parallel) = 16 ohms (internal resistance) + 16 ohms (external resistance) = 32 ohms.

Then as

$$C = \frac{E}{R}, \text{ we have } \frac{8}{32} = \frac{1}{4} \text{ ampère, the strength of the current.}$$

Under the conditions stated, the strongest current is produced by arranging the cells in two rows, with four cells of each row in series.

COMPOUND CIRCUITS.

Experiment 211.—With No. 16 insulated copper wire, make a compound circuit, as shown in Fig. 234. Insert a galvanometer (the first one made) in one branch at *G*.

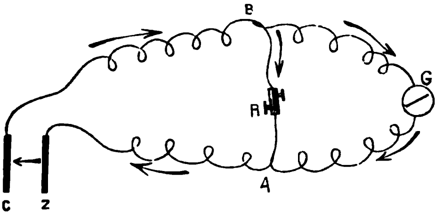

FIG. 234.

When the current reaches *B*, it divides, one portion going by the branch *B G A*, and the other portion by the branch *B R A*.

Either branch may be called a *shunt* (by-path) to the other.

Introduce at *R*, in the branch *B A*, the coil of one hundred feet of No. 16 copper wire used in Exp. 207. Note the deflection of the galvanometer. How does its deflection compare with its deflection before the coil was introduced at *R*?

Put in place of the coil of No. 16 wire the coil of No. 30 copper wire, also used in Exp. 207.

Compare the deflection of the galvanometer with its deflection when the coil of No. 16 wire was at *R*.

If when the coil of No. 30 wire was at *R* the resistance

of *B R A* was two ohms, and the resistance of *B G A* was one ohm, two-thirds of the current would flow through the circuit *B G A*, and one-third through *B R A*.

A compound or divided circuit may have more than two branches.

In a divided circuit the amount of current that will flow through different branches is inversely as their resistances.

CHEMICAL EFFECTS OF THE ELECTRIC CURRENT.

Experiment 212.—Procure two strips of platinum foil one inch long by three-eighths of an inch wide. Solder these to the ends of two pieces of insulated copper wire. Arrange the wires with the platinum electrodes at the ends, as shown in Fig. 235. Fill the glass vessel with water, and into this water pour a little sulphuric acid to increase its conducting power. Over each electrode invert a test-tube filled with the acidulated water (Fig. 235).

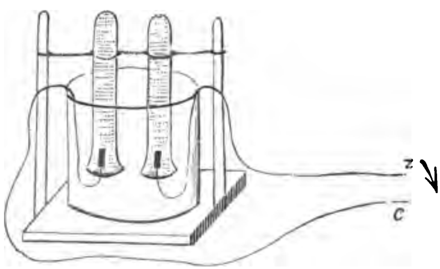

FIG. 235.

Connect the wires *Z* and *C* with two bichromate cells (see Appendix, § 6). You notice that bubbles of gas rise from each electrode, causing the water to sink in the test-tubes.

The gases are hydrogen and oxygen, the elements which are in combination in the molecules of water. The hydrogen will be found in the tube containing the more gas.

The element given off from the positive (+) electrode is the electro-negative element; the element given off from the negative (−) electrode is the electro-positive element.

Determine (see p. 239) which is the + electrode, and which the − electrode. Which gas is an electro-positive element? Which, an electro-negative element?

Insert a galvanometer in the circuit. Is the needle deflected? Has a current passed through the acidulated water?

Various other compounds in solution, as sulphate of copper, potassium iodide, may be decomposed by the current.

The decomposition of compounds by the electric current is called Electrolysis.

The compound itself is called an Electrolyte.

Experiment 213.—Put into a tumbler a strong solution of copper sulphate (blue vitriol). Couple two gravity cells in series. Attach to the wire leading from the copper element a strip of sheet copper an inch wide and two inches long. Attach to the end of the wire leading from the zinc element a small piece of iron, as an eight-penny cut-nail, thoroughly cleaned. See that all connections are thoroughly made. Immerse both the iron and the strip of copper in the solution of copper sulphate. Put the copper and the iron very near each other. Let them remain in

the solution for twenty-four hours. Upon removing the iron, you will find that a film of copper has been deposited upon the iron. The iron has been *electroplated* with copper.

The current of electricity passing through the solution of copper sulphate decomposes it, and the metallic copper is deposited on the body attached to the negative electrode. As fast as copper was taken from the solution and deposited on the iron, copper was dissolved from the sheet copper, thus keeping up the strength of the solution.

Nickel, gold, and silver may be deposited in the same manner, provided the bath used is a solution of a salt of the metal to be deposited.

MAGNETIC CONDITION OF A WIRE THROUGH WHICH A CURRENT IS PASSING.

Experiment 214.—Pass a piece of copper wire one-eighth of an inch in diameter through a hole in a piece of cardboard, as shown in Fig. 236. Use wire that is not insulated, as more obvious results are obtained.

Sprinkle iron filings on the cardboard around the wire. Connect this piece of copper with wire leading from a battery of five bichromate cells. Tap lightly the cardboard, and notice that the filings arrange themselves in circles round the wire.

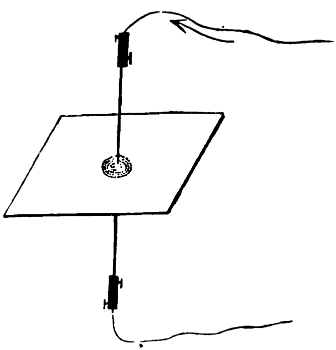

FIG. 236.

A conductor through which a current is passing is surrounded by Lines of Force* just as a magnet is.

Let the current pass in the direction indicated by the arrow (Fig. 236). Place a very small magnetic needle (see Appendix, § 7) near the copper. Notice which way the north pole is deflected. Place the needle in other positions round the copper, keeping it at the same distance from the copper. Notice each time which way the north pole is deflected.

Reverse the current (see Appendix, § 7), and put the needle in the same positions as in the former trial. Notice which way the north pole of the needle is deflected.

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* The phenomena of a steady electric current are not confined to the conducting wire, for the space surrounding the wire bearing a current is found to be in a peculiar condition—a condition which can be explained as due to displacement of the ether or other dielectric or medium filling that space, and one which it seems impossible physically to account for on any other satisfactory basis.

The condition of a space immediately surrounding a current may be explored by means of iron filings. If a conducting wire be passed vertically through a hole in a piece of card adjusted to a horizontal position, and if iron filings be then sprinkled upon the card, and if the card be gently tapped downwards so that the filings may leap into positions spontaneously assumed by them, they will be found to range themselves in concentric circles round the current, while each filing becomes, for the time being, a little magnet.

The space round the current is therefore an *Electro-magnetic Field of Force*, permeated by concentric circular *Lines of Force.*

The Lines of Force mark the direction in which an ordinary magnet, such as a small compass needle, when placed within the field, tends to place itself. The one end of the magnet is driven in one direction, the other end equally in the opposite direction, along these lines of force; the magnet is acted upon by a couple, which acts upon the two extremities, or poles, like the hands on the handles of a copying press—one pole being pushed or repelled, the other being pulled or attracted, until the magnet lies along a line of force.

The direction in which a current tends to throw the positive, or

Determining the Direction of the Lines of Force around a Wire.—If we apply Ampère's rule, we can determine the direction in which the lines of force set round a wire conveying a current. If we suppose the observer to be swimming in the current, he would pass, according to the direction we first gave the current, through the plane of the paper, head foremost; if, then, he looks at the needle *N S*, the north pole will turn in the direction of his left hand, as shown in Fig. 237.

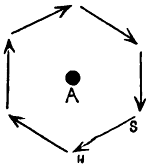

FIG. 237.

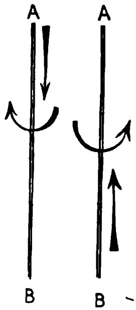

FIG. 238.

In Fig. 238 *A B* represents the copper wire, and the arrow indicates the direction of the current. When the current flows along the wire from *A* to *B*, the direction of the lines of force was right-handed, or in the direction of the motion of the hands of a clock, as shown by the curved arrow; when the current flowed from *B* to *A*, the direction of the lines of force was left-handed, or counter clock-wise. Or, to state it differently, if a person looks along a conductor *in the direction in*

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north-seeking, pole of a magnet placed in its neighborhood is shown by Fig. 239. This direction is called the *Positive Direction* of the lines of force. The current in the figure passes vertically upwards; the positive pole is thrown to the left hand of the current. This expression, "left hand of the current," is obtained by supposing the current to be replaced by a person whose head is at *B*, and feet at *A*, and who turns so as constantly to keep the magnet-pole in full view. The relation between the direction of the current and the positive direction of the lines of force is always the same as that between the propulsion of the point and the twist of the hand in the ordinary use of a corkscrew.—*Principles of Physics. Daniell.*

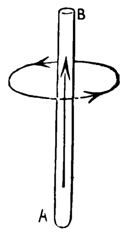

FIG. 239.

which the current is moving, the lines of force will be directed positively round the conductor in the *same direction as that in which the hands of a watch turn.*

Experiment 215.—Take two pieces of No. 16 insulated copper wire thirty inches long. File one end of each to a sharp point, and then bend each wire as shown in Figure 240. Procure two small copper cartridge-shells. Fill these with mercury and place them on the edge of a table. Hang the two wires in the shells so that the wires shall be parallel and less than a quarter of an inch apart. See that the copper shells do not touch each other. Let the wires dip half an inch into a tumbler of dilute sulphuric acid. From each shell lead out a wire *A* and *B*. Connect the ends of the wires *A* and *B* with a battery of five or six bichromate cells (see Appendix, § 6). The current now flows down one wire, through the acidulated water, and up the other wire. We have then two parallel currents moving in opposite directions. Make and break the connection quickly.

FIG. 240.

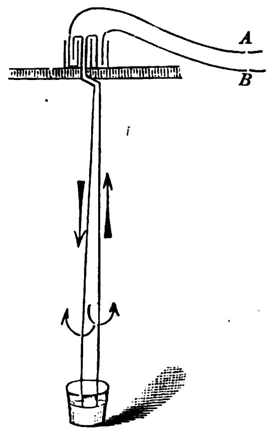

FIG. 241.

The wires repel each other.

Place the two shells upon a piece of sheet copper, so that they may be electrically connected, and lead one wire from

the battery to the tumbler of acidulated water, and let the other wire from the battery dip into mercury in one of the shells.

We have now two parallel currents flowing through the wires in the same direction. Make and break the connection quickly.

The wires attract each other.

If the direction of the lines of force round the wires is examined, we find that when the current in the wires is passing in opposite directions, the *adjacent* lines of force (Fig. 242) set in the same direction; and when the current in the wires is passing in the same direction, the

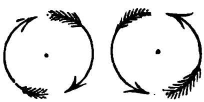

FIG. 242.

adjacent lines of force (Fig. 243) set in opposite directions. We have learned that like magnetic poles repel, and that unlike poles attract, each other. In the same manner, *lines of force directed alike repel, and those directed oppositely attract, each other.*

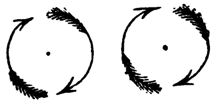

FIG. 243.

SPIRALS AND HELICES.

Experiment 216.—Procure a piece of iron wire one-eighth of an inch in diameter and nine inches long. Wind around this No. 16 insulated copper wire to within half an inch of each end. Let the wire be wound as if it were the thread of a right-hand screw (see p. 26). You have now formed a right-hand *spiral* or *helix.* The iron within the helix is the *core.* Turn the helix end for end

Is it still a right-hand helix? Would the turn of the right hand and wrist from you propel the spiral forward, no matter which end of the spiral was held in the hand? Connect the ends of the wires of this right-hand helix with the battery of one or two bichromate cells. The core inside the helix becomes a magnet. Now, knowing the direction the current is flowing through the helix, determine, by applying Ampère's rule, the polarity of the ends of the core.

Remember that taking any particular part of the wire you imagine yourself swimming in the current so as to look at the core, then the north pole will be towards your left hand. When you have determined the polarity, prove whether you have reasoned correctly, by bringing the pole of a magnetic needle near the poles of the core.

In a right-hand helix the north pole of the core is at the end where the current leaves the helix.

Experiment 217.—With the same piece of iron for a core and insulated wire of the same size, make a *left-hand* spiral.

Determine by Ampère's rule the polarity of the ends of the core, and prove that your reasoning is correct, by passing a current through the spiral, and bringing the poles of a magnetic needle near the poles of the core. Write out the law for determining the poles of a left-hand helix.

Test.—Examine any electro-magnet, ascertain the kind of helix, fix the direction the current is to take, and then determine the poles of the core.

THE SOLENOID.

Experiment 218.—Make a solenoid three inches long, similar to that shown in Fig. 244, by winding insulated copper wire No. 20 around a lead-pencil. The wire must be wound so that one turn lies close to the next, not separated as in Fig. 244.

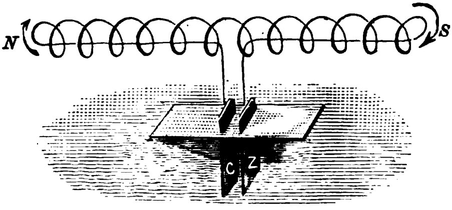

Fig. 244.

Put a strip of copper and one of amalgamated zinc, each one and a half inches long by half an inch wide, through a large cork or piece of light wood, and connect the ends of the spirals to the strips, as shown in Fig. 244. Float the apparatus in a bowl of dilute sulphuric acid. A current passes through the solenoid in the direction indicated by the arrows.

Prove this by Ampère's rule.

Present the north pole of a bar magnet to the end of the solenoid marked *N.* What is the result?

Present the south pole of the bar magnet to the end of the solenoid marked *N.* What is the result? The solenoid acts as a magnet.

To what is this due? Before we can understand it fully we must perform the following experiment:

Experiment 219.—In Exp. 214 we saw that a conductor through which a current is passing is surrounded by lines of force. Fit up a piece of apparatus like that shown in Fig. 245, but instead of one wire, as in Exp. 214, use two

wires, letting them pass through the card a quarter to three-eighths of an inch apart.

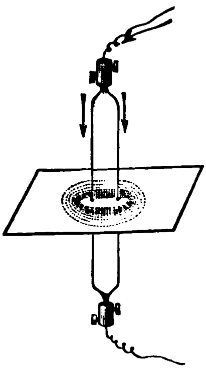
FIG. 245.

Connect the wires with a strong battery, and the current will flow through each wire in the same direction. Sprinkle iron filings around the wires, and gently tap the cardboard. The filings will be found to arrange themselves in a curve around both wires, as shown in Fig. 245, showing that the tendency of the lines of force is to surround both wires. Should we use three or more wires the lines of force would tend to surround them all.

Explanation.—Suppose we should cut down through the

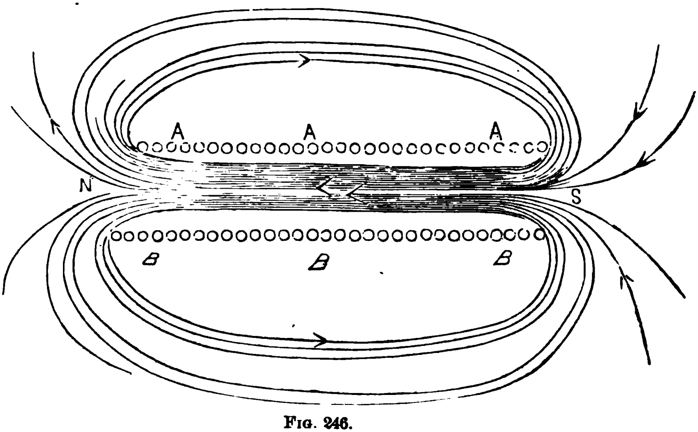

FIG. 246.

solenoid used in Exp. 218 with a plane, the small circles

A A A and *B B B* would represent sections of the wire (Fig. 246).

The lines of force, instead of surrounding each wire separately (Exp. 218), unite and surround all the wires.

The lines of force then are crowded together through the inside of the solenoid, and spread through a larger field outside the solenoid. If we apply Ampère's rule we shall find the lines of force entering at *S* and leaving at *N* (Fig. 246). Verify this by applying the rule.

The crowding together of the lines of force gives the great strength of the field within the solenoid.

Within the solenoid the lines of force are conducted through the air. The conducting power of iron is seven hundred times as great as that of air, and so were we to put a piece of iron, of the same length as the solenoid, in the solenoid as a core, the number of lines of force produced by the current in the wire would be increased, and the solenoid would exhibit stronger magnetic properties at its ends.

Experiment 220.—Procure a piece of wood three by four inches and one-eighth of an inch thick (a piece of cigar box will answer), and cut two slits in the centre half an inch apart. Into these put the ends of a piece of copper and a piece of amalgamated zinc, each piece one and a half inches long by half an inch wide. Make a coil of twenty turns of No. 30 insulated copper wire, fastening the wire together, and also the coil to the wood, with sealing-wax. Connect one end of the coil with the zinc and the other end with the copper strip (Fig.

Fig. 247.

247). Float the coil upon a bowl of dilute sulphuric acid. Present the north pole of the bar magnet and then the south pole to the same side of the coil, and explain in each instance the movement of the floating coil.

INDUCED CURRENTS.

Experiment 221.—Wind around a piece of quarter-inch round iron, three and a half inches long, one hundred and eighty turns of No. 30 insulated copper wire (see *C*, Fig. 248).

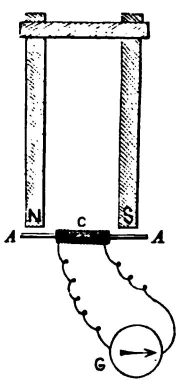

FIG. 248.

Place two bar magnets on the edge of the table, letting them project two inches over the edge. Across the other ends lay a piece of soft iron to act as an armature. Connect the ends of the wire coil with a sensitive galvanometer G (see Appendix, § 8). Now, when the armature *A A* is in contact with the poles *N* and *S*, quickly draw it away, and notice that the needle of the galvanometer is deflected. A current is produced in the coil *C*. Be careful that currents of air caused by quick movements in drawing the armature away do not affect the galvanometer.

Next hold the armature *A A* sufficiently far away from the poles *N* and *S* to be beyond the lines of force which pass from one pole to the other. Move the armature *A* quickly towards the poles, bringing it as near as possible without letting the iron touch the poles.*

* A piece of paper folded and placed over the ends of the poles will aid in performing the experiment.

Note that the needle of the galvanometer is deflected. A current is again produced in the coil *C*. Was the needle deflected in the same direction as when the iron was drawn away from the poles *N* and *S*?

Explanation.—Between the poles *N* and *S* lines of force are passing (Fig. 249). When the armature *A* is against these poles there are more lines of force passing between the poles, because iron as a conductor of them is much better than air. The lines of force which pass through the armature *A A* also pass through the coil *C*. Now, as the coil is drawn away from *N* and *S*, the number of lines of force passing through it constantly diminishes or changes.

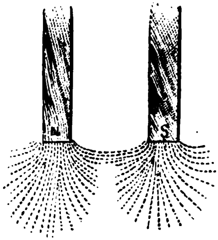

FIG. 249.

As the coil is moved towards the poles *N* and *S* the number of lines of force constantly increases or changes. In either case there is a *change* in the number of lines of force passing through the coil.

A change in the number of lines of force passing through the space enclosed by a coil of wire produces a current of electricity in the wire.

Experiment 222.—Make a hollow cylinder two and a half inches long, having an inner diameter of one and one-eighth inches, by rolling up a strip of manila paper, and fastening it with mucilage. Slip over the ends of this hollow cylinder two flat rings of cardboard one and one-eighth inches inside diameter, and one and a half inches outside diameter, and fasten them with glue. Next wind

about the cylinder nine hundred turns of No. 30 insulated copper wire. The rings projecting beyond the cylinder prevent the wire from slipping off. Shellac each layer of wire to hold it in place. Connect the ends of the wire coil with the galvanometer used in the preceding experiment.

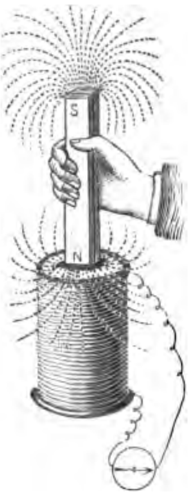

FIG. 250.

Place the two bar magnets side by side with their north poles together, and quickly plunge the magnets, north pole first, into the coil, as shown in Fig. 250. Notice that a current is produced.

Determine by the deflection of the galvanometer needle in which direction the current is passing in the helix.

Withdraw the bar magnet quickly. Again a current is produced in the helix. What is its direction when compared with the direction of the current produced by plunging in the magnets?

Put the south poles of the magnets together. Plunge these quickly into the helix. How does the direction of the current compare with the direction caused by plunging in the north poles? Withdraw the south poles. Compare the direction of the current with its direction when the north poles were quickly withdrawn.

What must be the movement of the north poles to give a current in the same direction as that produced when the south poles are withdrawn? What, when the south poles are plunged in?

Lay the helix on its side, thrust into one end either pole

of the magnet, and then suddenly take it out by pulling it through the coil. What is the result?

Explanation.—As the bar magnet goes down into the helix (Fig. 251), the number of lines of force passing through the space enclosed by the coils is increased, because, as the magnet enters, lines of force pass through the area enclosed by the first coil, then through the area enclosed by the second coil, while continuing to pass through the area of the first, and so on for the third coil, and the other coils below it.

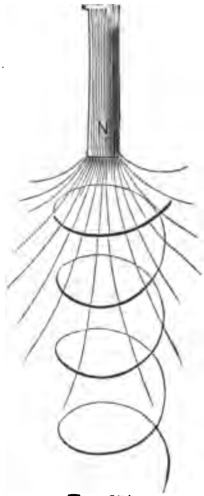

FIG. 251.

As the bar magnet is removed, the number of lines of force passing through the space enclosed by all the coils is decreasing, because the lines of force first cease to pass through the area enclosed by the last coil, then cease to pass through the area enclosed by the coil next above, and so on.

Increasing the number of lines of force passing through the space enclosed by a coil of wire produces a current in the coil in one direction; decreasing the number of lines of force, produces a current in the opposite direction. In each instance the direction of the current depends upon the direction of the lines of force.

Experiment 223.—Make a helix of coarser wire to fit inside of the helix used in Exp. 222, by winding about a hollow paper cylinder one hundred and fifty turns of No. 24 insulated copper wire.

Connect the ends of the coil of coarser wire *A* and *B* with three bichromate cells. Lines of force are produced around the coarser coil, as shown by the dotted lines in Fig. 252. Connect the ends of the coil of finer wire with the galvanometer. Plunge the coil of coarser wire quickly into the coil of finer wire. Note the deflection of the galvanometer needle. A current is produced in the coil of finer wire. Withdraw the coil quickly. A current is produced in the opposite direction.

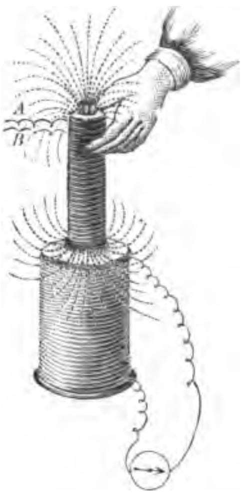

FIG. 252.

The current produced in this way is known as an *induced* current, as is also that when a magnet is thrust into a coil.

The coil through which the electric current is passing is called the *primary* coil; the coil in which a current of electricity is induced is called the *secondary* coil.

Determine, by the direction of the current in the primary coil, the polarity of the ends of this coil, and see whether the currents produced by putting the primary coil into the secondary coil and taking it out agree in direction with the currents produced in the secondary coil by putting in and taking out the same poles of the bar magnet.

Reverse the current in the primary coils (see Appendix, § 7), quickly plunge it into the secondary coil, and then withdraw it. In what direction do the currents flow in the secondary coil?

Pack the inside of the primary coil with pieces of iron wire. Pass a current through the coil, and plunge it into the secondary coil. A stronger current is produced in the secondary coil. Can you explain why?

The Induction Coil.—Fig. 253 shows a Ruhmkorff's induction coil. In the induction coil the object is to secure an induced current of high E. M. F. as compared with the E. M. F. of the battery current. The coil consists of coarse wire coiled a few times around a bundle of soft iron wires. This is called the *primary* coil (see Exp. 223). Outside the primary coil is the *secondary* coil (see Exp. 223), which consists of a great number of turns of fine wire.

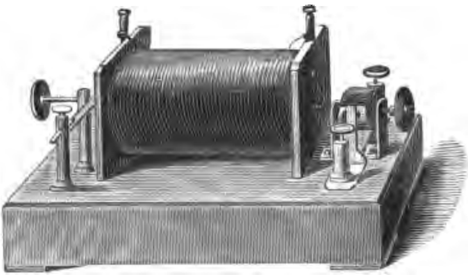

FIG. 253.

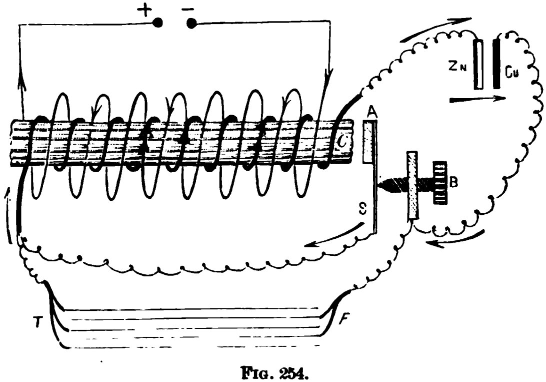

FIG. 254.

Fig. 254 represents a section of the coil. The arrows indicate the direction of the primary and of the secondary current at the instant the circuit is closed.

When the current flows through the primary coil, the end *C* of the core becomes a strong electro-magnetic pole, and attracts the little hammer-shaped piece of soft iron *A* attached to a stiff spring *S*. Contact is made with this spring by an adjustable screw *B*. As the electro-magnetic pole *C* attracts *A*, the circuit is broken. Instantly the core ceases to be an electro-magnet, and the hammer is carried back by the stiff spring *S*, and the circuit is again closed. In this way the circuit is rapidly made and broken, and a current is induced in the secondary coil (Exp. 223).

The *condenser* *T F* consists of sheets of tin-foil separated from each other by silk or paper soaked in paraffine. The alternate sheets of tin-foil are connected with the opposite terminals of the *contact-breaker* *A*, *S*, and *B*. The object of the condenser is to prevent the current from leaping across from the screw to the spring each time the contact is broken.

The induced currents produced by an induction coil are capable, like frictional electricity, of yielding sparks by overcoming the resistance of the air between the knobs marked + and – in Fig. 254.

The electricity produced is of high tension or E. M. F. (measured in volts) as compared with the E. M. F. of the primary current. On the other hand the strength of current in the secondary coil (measured in ampères) is much less than that of the primary coil.

THE TELEPHONE.

Experiment 224.—Make a weak bar magnet *A* (Fig. 255) by magnetizing a piece of steel a quarter of an inch in diameter and three inches long. Around one pole wind

a hundred turns of No. 30 insulated copper wire *B*, and connect one end of the wire with two gravity cells, so that the current will flow in the direction that will strengthen

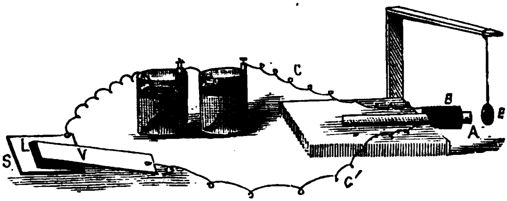

FIG. 255.

the magnet; that is, if the wire is wound around the south pole of the magnet, the direction of the flow of the current when one looks at the face of the south pole must be the same as the direction in which the hands of a watch move.

In front of the magnet suspend by a thread or strip of paper a disk of tin (or sheet iron) *E*, the size of a dime. Connect the other battery wire with a piece of tin *S* about two inches square, and the remaining wire *C′* from the coil with a strip of tin *V*. On *S* pile up a little dry lamp-black *L*, and press it with the strip *V*, being careful not to allow the two pieces of tin to come into contact. The lamp-black will be compacted into a thin cake. If the disk *E* be the right distance from the magnet *A*, it will answer to every pressure of the finger upon *V* by a quick movement towards the magnet. This experiment illustrates the principle that the power of carbon to transmit a current of electricity varies directly with the pressure upon the carbon. What causes the movement of the disk *E*?

Description of the Telephone.—In Exp. 224 we have the essential parts of the telephone. The only difference is

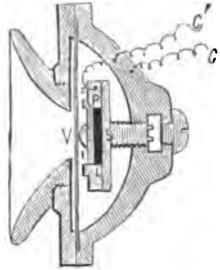

FIG. 256.

that the plate *V*, instead of being pressed by the finger, is caused to vibrate by the sound waves of the voice striking against it; and the disk *E*, instead of being suspended, is firmly fixed close to the magnet, so that it vibrates in exact accordance with *V*, and reproduces the sound waves that set *V* into vibration. Fig. 256 is a sectional view of the mouth-piece, or *transmitter*, of the telephone, now generally used. *V* is the vibrating metallic diaphragm; *I* is an ivory button, which conveys the motion to *P*. *P*, the white strip in Fig. 256, is a piece of platinum foil resting upon a button of compressed lamp-black *L*. One wire *C′* is attached to the platinum, and the other wire *C* to the standard *S*, which is in contact with *L*.

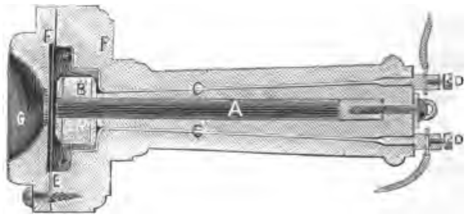

FIG. 257.

Fig. 257 represents a sectional view of the *receiver*, shown in Fig. 258. *A* is the permanent magnet; *B* is the coil; *C C* are the wires from *B* to the binding-screws *D D*. *E* is a vibrating metallic disk. The corresponding parts in the figures are marked with the same letters.

FIG. 258.

THE DYNAMO.

We have seen (p. 275) that a change in the number of lines of force that pass through the area of a coil of conducting material will produce a current of electricity in the wire constituting the coil. The dynamo-electric machine generates electricity upon this principle, in causing, by mechanical means, a change in the number of lines of force that pass through the area enclosed by coils of electric conductors.

Fig. 259 shows a rectangular coil of wire *C*, that may be revolved about the axis *O X* between the grooved poles of

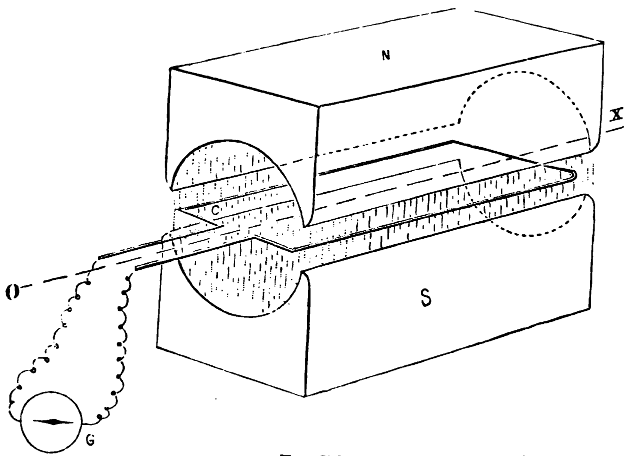

FIG. 259.

two powerful magnets *N* and *S*. The ends of the coil *C* are connected to the galvanometer *G*. The lines of force that exist between the poles *N* and *S* are indicated by the dotted lines. Fig. 260 shows an end view of Fig. 259. Here the coil C is shown in four different positions (*A*, *B* *C*, and *D*) of its rotation about its axis *O X*. When in the position *A E* the greatest number of lines of force pass through the area of the coil. When the coil has

moved to the position *B*, one-eighth of the way around, a less number of lines passes through this area. When turned to the position *C*, one-quarter of a revolution, no lines pass through the area of the coil, because its plane is parallel to the lines of force.

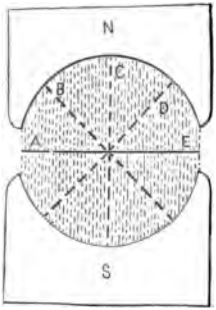

FIG. 260.

But the strength of the current depends upon the rapidity of the change in the number of lines of force passing through the coil.

If the lines of force represented in Fig. 260 are examined, it will be seen that the number of lines that the coil passes out of in the first eighth of its revolution, or from *A E* to *B*, is less than the number it passes out of in the next eighth of a revolution, or from *B* to *C*. Or, to state this fact generally, in the revolution of the coil from *A E* to *C*, the number of lines of force that the coil passes out of at each successive moment is greater than the number it passed out of during the preceding moment. Hence, the strength of the current in the coil constantly increases during the revolution from *A E* to *C*.

In the passage of the coil from *C* to *E A* the conditions are the reverse, and the strength of the current in the coil constantly decreases.

The fact that during this quarter of a revolution the number of lines of force is increasing, and not decreasing as in the revolution from *A E* to *C*, would produce a current in the opposite direction, were it not that the lines of force pass through the coil from the opposite side. Thus we see that the current in the coil flows in the same direction during the first half of its revolution.

But as the coil moves on from *E A* through the third quarter of a revolution, the lines of force again decrease in number, continuing, however, to pass through the coil from

the same side. Hence, as the coil leaves position *E A*, the current changes to the opposite direction. This direction is maintained throughout the second half revolution, for the same reasons that the current is maintained in one direction during the first half revolution.

Now, if the galvanometer *G* (Fig. 259) is watched while the coil *C* is revolved clockwise from position *A E* (Fig. 260) to position *E A*, or one hundred and eighty degrees, the needle will indicate that a current of electricity is generated, which at the start is nothing at position *A E*, and constantly increases till position *C* is reached, and then again decreases till position *E A* is reached, where it is again nothing. If the rotation is continued through the other half revolution, the needle will indicate that a current, increasing and

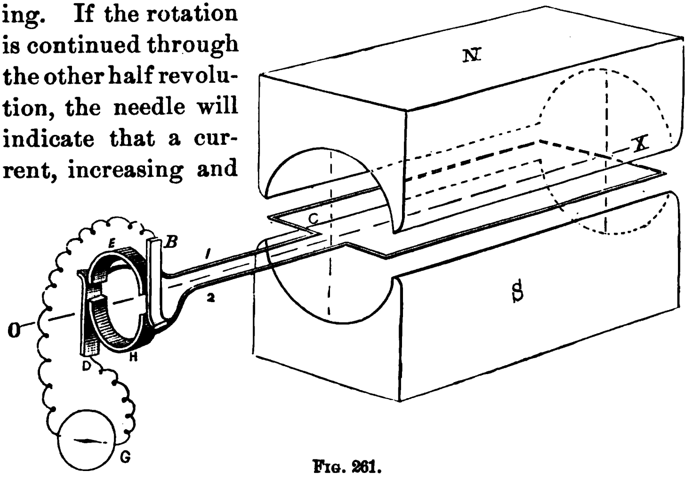

Fig. 261.

then decreasing again, is generated in the coil, but in an opposite direction to that generated in the first half revolution.

With the construction shown in Fig. 259 it is impossible to revolve the coil *C* without twisting the wires leading to the galvanometer *G*; hence the constructions shown in Fig. 261.

In Fig. 261 the ends of the coil *C* are connected to two

semicircular metal bars; the end 1 being connected to bar *E*, and the end 2 to bar *H*. These bars lie in a circle, through the centre of which the line *O X* passes. The bars *E* and *H* are separated by a small space, and two *brushes* *B* and *D*, made of thin sheets of copper, are prepared to lie on the circular bars at the opposite ends of a horizontal diameter. With the brushes a galvanometer *G* is connected. With this arrangement the coil *C* can be revolved about the line *O X*, and yet an electrical connection be maintained between the coil and the galvanometer. Fig. 262 is an end view of Fig. 261, with the coil in a position *C* at right angles to a line between the centres of the poles *N* and *S*. In this position the brushes *B* and *D* lie across the open spaces between the bars *E* and *H*, touching both bars.

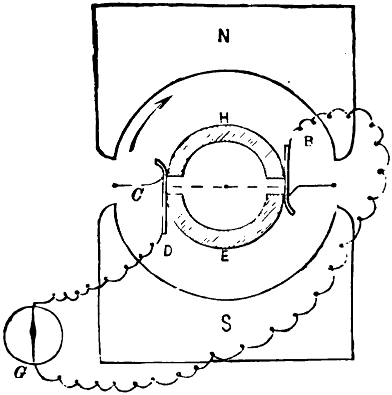

FIG. 262.

Now rapidly revolve the coil clockwise until the plane of the coil includes the line drawn between the centres of the poles. Fig. 263 (*C*) shows this ...n of the coil. Here the brush *D* lies on bar *E*,

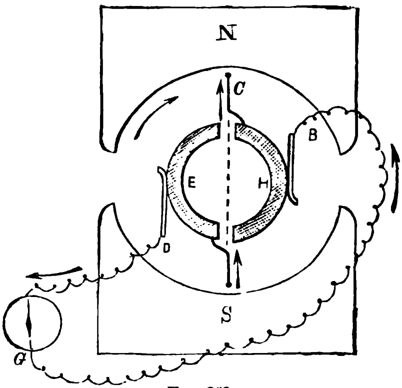

FIG. 263.

and brush *B* on bar *H*. Following the law for the direction of the current produced by this motion (see p. 277), a current will be produced in the coil, which will flow out of the brush *D* on bar *E*, and into brush *B* on bar *H*. Continuing the revolution of the coil through the next ninety degrees, the position shown in Fig. 264 is reached, the first half revolution having been completed. During this motion the current generated will continue to flow from the brush *D* and into the brush *B*, according to the law above referred to. But the current produced becomes weaker and weaker through this second quarter of the revolution, until at the position shown in Fig. 264 no current is produced, and the brushes again rest on the open space between the bars. Then continue the motion through the third quarter, when the coil stands in the position shown in Fig. 265.

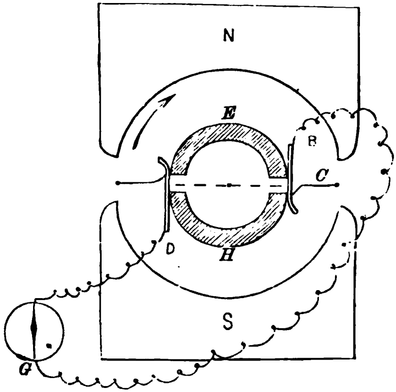

FIG. 264.

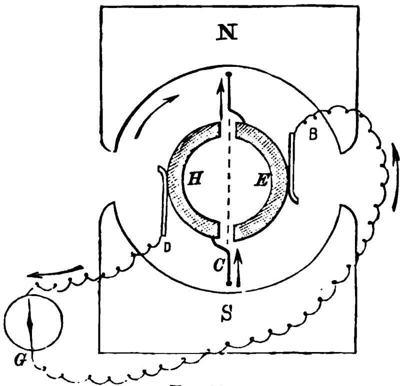

FIG. 265.

And again, if the law for the direction of the current produced be followed, it will be found that, as before, the cur-

rent flows from brush D, which is now on bar H, and into brush B, which rests on bar E; that is, the current flows in the same direction through the fourth quarter of the revolution. Hence, by means of the stationary brushes resting on the two bars, which revolve with the coil, the current, alternating in direction once for every half revolution of the coil, is conveyed to the two brushes, so that it always flows out of one brush D, called the *positive brush*, and into the other B, called the *negative brush*.

This changing of the alternating current in the coil to a continuous one in the circuit to which the brushes lead is called *commutation*, and the bars E and H are called the *commutator*.

When the coil C is wrapped about an iron cylinder, the wire and iron together constitute the *armature;* the iron is the *armature core*, and the *wire* is the *armature winding*. The coil C is, in this case, an *armature coil* of *one turn*.

When there is but one coil on the armature, the current obtained from the brushes, although always in one direction, will vary in strength from nothing when the plane of

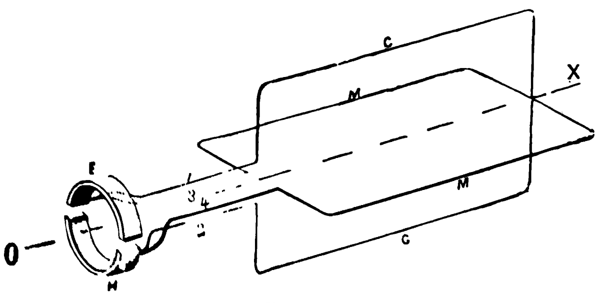

FIG. 266

the coil is in the position A E (Fig. 260), to the maximum strength of current when the plane of the coil is in the position C (Fig. 260).

This varying strength in the current would be nearly removed by wrapping another coil *M* (Fig. 266) about the armature core, with its plane at right angles to the plane of coil *C*. The end 1 of coil *C* would be connected to bar *E*, and the end 2 to bar *H*; the end 3 of coil *M* would be connected to bar *E*, and the end 4 to bar *H*.

Furthermore, four coils evenly distributed around the armature core, and properly connected to a four-bar commutator, would give a still smoother current than the two-coil armature, illustrated in Fig. 266. The plan of connecting a four-coil armature to its commutator is shown in Fig. 267, where coils *A*, *B*, *C*, and *D* have their ends 1 and 1′, 2 and 2′, 3 and 3′, 4 and 4′, respectively, connected to bars *N* and *V*, *V* and *W*, *W* and *M*, *M* and *N*. The front end only of the armature is shown in Fig. 267.

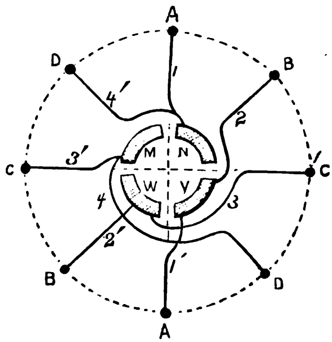

FIG. 267.

By increasing the number of armature coils and the number of commutator bars, a still smoother current could be obtained from the brushes. In machines of any considerable size, the practice is to have from thirty to fifty coils of from one to twelve turns each on an armature. The commutator bars are insulated from each other by mica.

The magnets between whose poles the armature rotates are called the *field magnets* of the dynamo. The first dynamos, or so called magneto-electric machines, had permanent magnets for the field magnets, but now these are never used when a considerable current is desired. The practice is to use electro-magnets for the field, and the current to excite these magnets is usually furnished by the

rent flows from brush D, which
brush B, which rests on bar E;
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FIG. 200

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This varying strength in the current ... removed by wrapping another coil ... armature core, with its plane at right angles ... of coil C. The end 1 of coil C ... E, and the end 2 ... connected to bar E, and the end ...

Furthermore, four coils evenly distributed ... armature core, and properly connected ... mutator, would give a still smoother current ... coil armature, illustrated in Fig. ... ing a four-coil armature ... 267, where coils A, B, C, and D ... 2 and 2', 3 and 3', ... N and V, V' and W, W' and ... M, M and N'. The front end only of the armature is shown in Fig. 267.

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The magnets ... are called the field ... dynamos, or ... ment magnets ... rarely ...

rent flows from brush *D*, which is now on bar *H*, and into brush *B*, which rests on bar *E*; that is, the current flows in the same direction through the fourth quarter of the revolution. Hence, by means of the stationary brushes resting on the two bars, which revolve with the coil, the current, alternating in direction once for every half revolution of the coil, is conveyed to the two brushes, so that it always flows out of one brush *D*, called the *positive brush*, and into the other *B*, called the *negative brush*.

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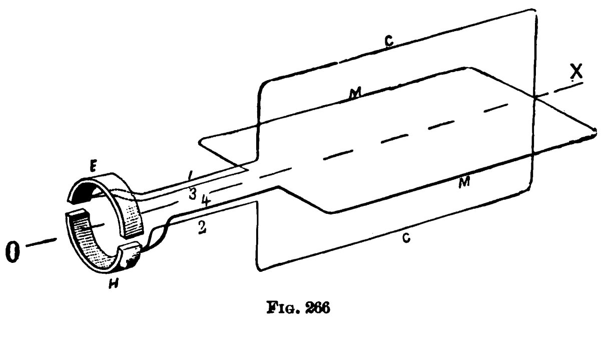

FIG. 266

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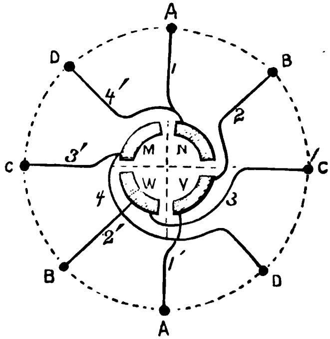

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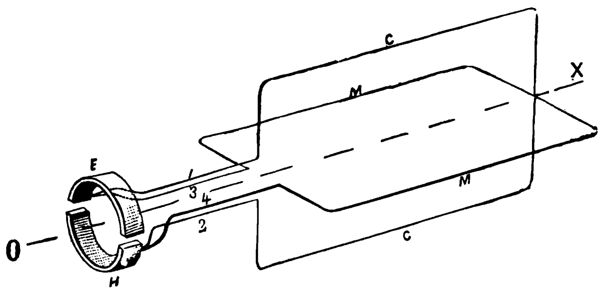

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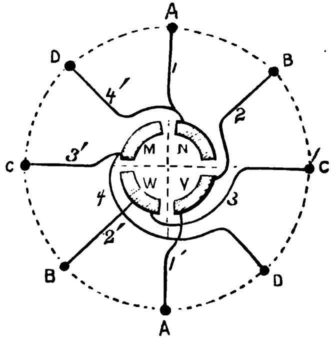

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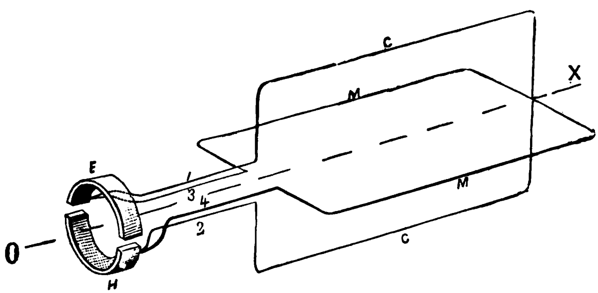

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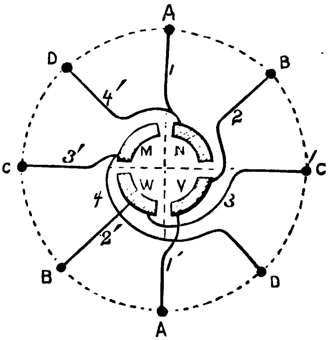

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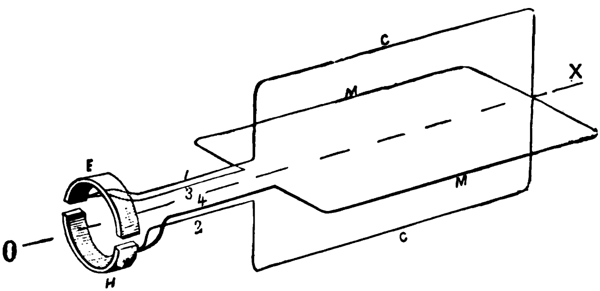

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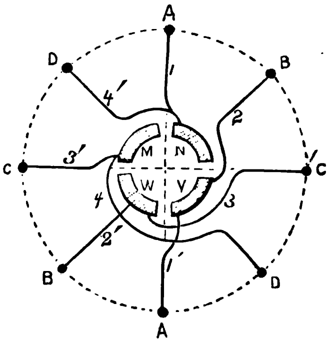

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dynamo itself. The two simplest forms of connecting the field winding to the armature winding are shown in Figs. 268 and 269. In Fig. 268 the positive brush is connected with one end of the field windings, and the other end of the field windings is connected to one end of the working circuit, which, in the case illustrated, consists of arc lamps; the negative brush is connected with the other end of the working circuit.

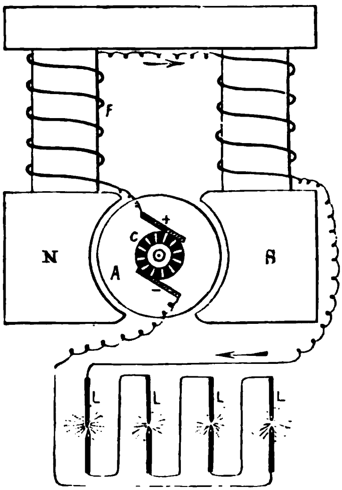

FIG. 268.

The field magnet is magnetized at first at the factory, and after a dynamo is run for the first time, the field cores retain sufficient magnetism, so that the machine when started again generates a small current as a magneto-electric machine. This current passes through the field windings, and thus, by increasing the pole strength, increases the current generated. This increased current also passes around the field cores, and thus the current generated increases until the full capacity of the machine is reached.

The dynamo illustrated in Fig. 268 is known as *series wound*, because the field windings are in series with the armature and working circuit.

Another type is illustrated in Fig. 269. Here the positive brush is connected to one end of the field winding, and the negative brush to the other end of the field winding. These brushes are each connected to an end of the working circuit, which in this case consists of incandescent lamps. This is known as the *shunt wound* dynamo, because the

field winding forms a *shunt*, or other path, for the current from the armature than the working circuit. In other words, at the armature terminals the current divides, part going through the field windings, and part through the working circuit.

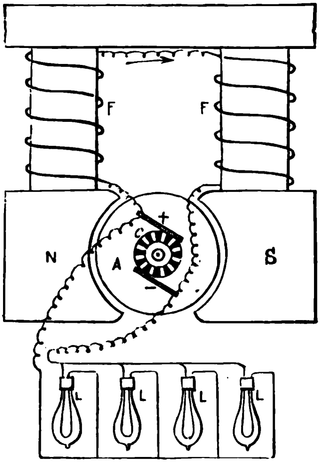

FIG. 269.

From what has been written, we see that in a dynamo there are two principal parts: first, the *field*, which includes the field cores and connecting metal, the field poles and the field windings; second, the armature, which includes the armature core, armature windings, and commutator. The office of the field of the dynamo is to produce a field of magnetic force, so placed that the armature may revolve in it.

A modern type of dynamo is illustrated in Fig. 270. Here A is the armature; C the commutator; B, and B' on the opposite side, the brushes; N and the corresponding piece at the base, the poles; and F and F', the field windings, or coils.

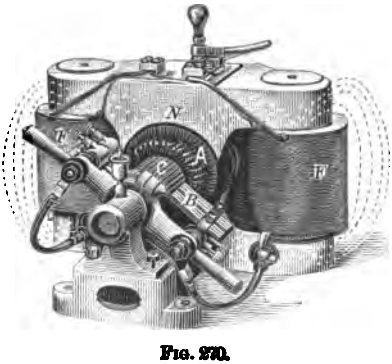

FIG. 270.

Now we have seen (p. 266) that a wire conveying a current of electricity is surrounded by a field of magnetic lines of force. In the

machine here shown, the lines of force surrounding the current in that part of the field windings next to the armature include the armature in their circuit from pole to pole. This is the useful part of the field windings. But, as indicated by the dotted curved lines (Fig. 270), there is a part of each turn of the field coils, the current in which does not aid in producing a useful field, for the negative whirls about this part of the field windings complete their circuits through the air, and hence do not pass through the armature.

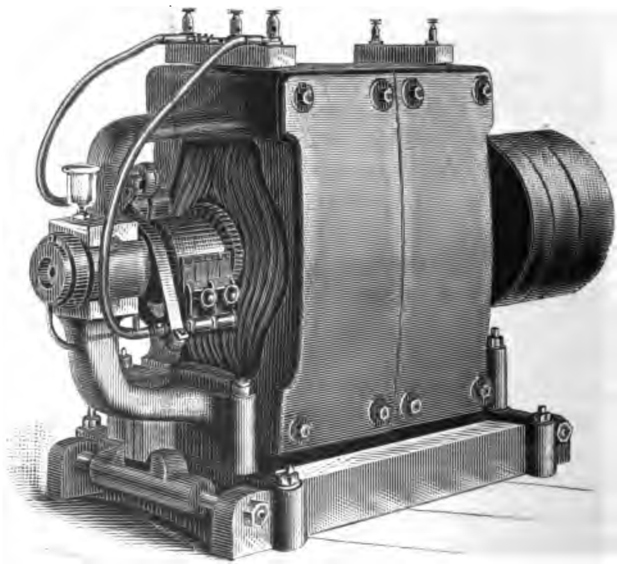

FIG. 271.

In the Eickemeyer dynamo (Fig. 271), the current in the field coils is quite completely used for furnishing a useful field.

Fig. 272 shows the machine with one side and one half

of the field windings removed. Here it will be seen that the field coils encircle the armature, so that the armature core is not only the core for the armature windings, but also serves the same purpose as the field cores in the style of machine illustrated in Fig. 270.

Therefore, all of the lines of force generated by the current in the field windings must include the armature core in their circuits, and thus all of them aid in producing the magnetic field of force for the machine.

The field coils of the Eickemeyer dynamo are so sur-

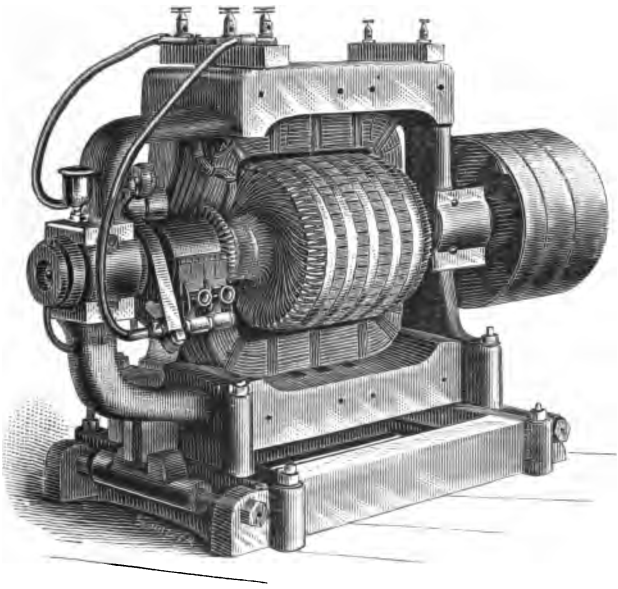

FIG. 272.

rounded by iron that the lines of force produced by the current in the field are quite entirely confined within the machine, and the dynamo when working at full capacity shows very little external evidence of magnetism.

MOTORS.

The opposite of the dynamo-electric machine is the electric motor. In the dynamo a current of electricity is generated by mechanically revolving the armature; in the motor the armature is revolved by the action of a current of electricity sent through the machine. A simple way of treating the action of the currents in an electric motor is illustrated in Fig. 273, where a current generated by a dynamo enters the field coils, passing through them enters the armature at the negative brush, and passing around the armature, through its several coils, leaves the positive motor brush, and so returns to the generator.

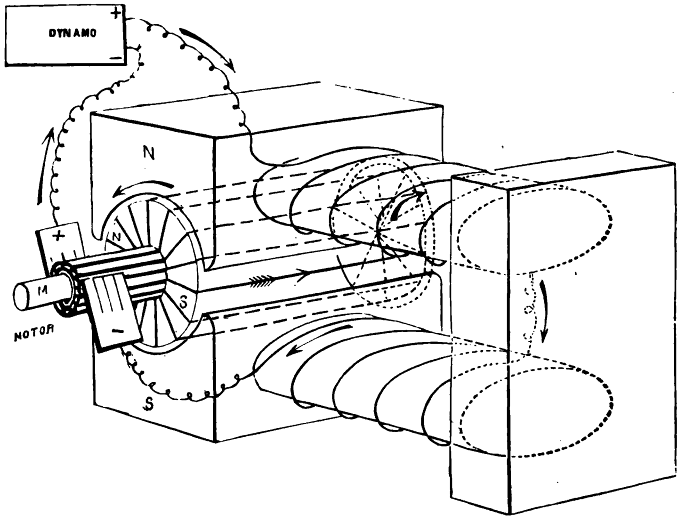

FIG. 273.

The current in the field coils produces poles *N* and *S* respectively, above and below the armature, and the current around the armature produces poles in the armature

core N and S respectively, at the left hand and right hand sides of the armature.

The south pole in the armature and the north pole in the field mutually attract each other, while the south pole in the armature and the south pole in the field mutually repel each other (see p. 273). The north pole in the armature and the south pole in the field mutually attract each other, while the north pole in the armature and the north pole in the field mutually repel each other. These attractive and repellent forces all tend to produce rotation in the armature, in a counter clockwise direction, as indicated by the curved arrow. And as the armature revolves, the armature poles advance and recede through the space occupied by one armature coil, as the commutator bars successively pass under the brushes.

As the armature revolves, power is taken by a crank or a pulley from the shaft M.

HEATING AND LUMINOUS EFFECTS OF ELECTRICITY.

Experiment 225.—Put a piece of No. 30 insulated German silver wire, about seven inches long, in circuit with three bichromate cells arranged in series. Let the current pass through the wire for three or four minutes. Take the wire in the hand; note whether there is any change in the temperature of the wire as compared with its temperature just before it was introduced into the circuit.

An electric current passing through a conductor of small diameter and great resistance will generate intense heat in the conductor.

The Incandescent Lamp.—Lamps constructed on the principle stated above are called *incandescent lamps.* In the globe of the lamp there is a conductor of small diameter,

which is heated white hot, or to incandescence, by the current. Fig. 274 shows an Edison incandescent lamp. In the glass bulb, *B* is the filament of carbon, which is fastened at its lower end to two small platinum wires, one of which is connected with the brass screw *D*, and the other with the brass disk *E*. The brass screw *D* and the disk *E* are insulated from each other by a layer of plaster of paris. When the globe is screwed into its socket, connection is made with the current by turning the thumb-screw shown in the figure at the right of the socket.

FIG. 274.

The filament in the Edison lamp is made of carbonized bamboo, and has a high resistance. All air must be removed from the bulb, otherwise when the filament is heated to incandescence it will quickly burn out because of the oxygen contained in the air. Accordingly the air is exhausted from the globe by means of a mercury pump. The standard incandescent lamp requires from one-half to three-fourths of an ampère of current, and an E. M. F. of one hundred volts to produce a light of sixteen candle power.

Incandescent lamps are usually connected parallel, as shown in Fig. 269.

The Arc Lamp.—If a conductor conveying a current of electricity from a powerful dynamo or battery be cut in two, and the ends separated about an eighth of an inch, the current will leap across the space between the ends of the wires. The air between the two ends offers great resistance to the passage of the current, and intense heat is generated. So great is the heat that the ends of the wire become white hot and melt away. If to the end of each wire a stick of carbon is attached and the ends of the carbon separated a very short

distance, the ends of the carbon will be heated to incandescence. A small quantity of carbon is volatilized, and this carbon vapor, intensely heated, forms a luminous arc of great brilliancy (called the *voltaic arc*) between the carbons. The dazzling light is due to the white-hot ends of the carbon and to the luminous arc.

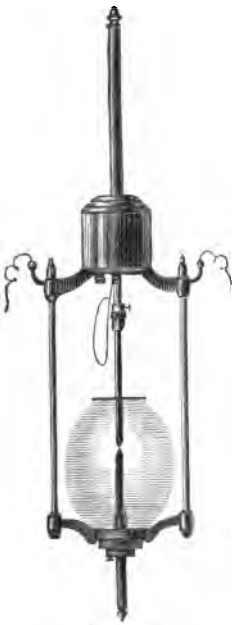

Fig. 275.

The arc lamp, shown in Fig. 275, involves the principle stated above.

The carbons are called electrodes. The positive electrode is the one from which the current flows, and is usually the upper carbon in arc lamps. The lower carbon is the negative electrode. The carbons burn away, and there is a mechanical device working automatically that keeps the carbons the proper distance apart.

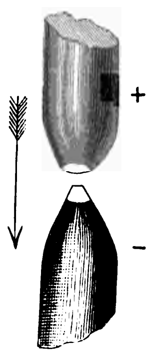

Fig. 276.

The positive electrode is hollow at the end (Fig. 276), and burns away twice as fast as the negative electrode.

Arc lamps are connected in series (see Fig. 268). An ordinary lamp requires from forty to fifty volts E. M. F., and from five to ten ampères of current. A circuit of fifty such lamps would require from two thousand to twenty-five hundred volts E. M. F.

THE STORAGE BATTERY.

Experiment 226.—Cut out of sheet lead two plates six inches by four inches, and punch smoothly in each as many

quarter-inch holes as possible. Make a paste of litharge and twenty per cent. solution of sulphuric acid, and fill the holes of the plate with this paste, spreading it with a brush on both sides of the plate. Now make another paste of red lead and twenty per cent. solution of the acid, and with it fill the holes and cover both sides of the other plate. After letting the plates dry thoroughly, bind them together with stout cord, keeping them about half an inch apart by means of a strip of wood placed at the top and at the bottom. Wires should be attached to the top of the plates.

To store this battery, immerse the plates, bound together as described, into a twenty per cent. solution of sulphuric acid, and connect the wires with the poles of a strong battery. After letting the apparatus stand for an hour or so, disconnect the battery cells from the plates, and connect the wires leading from the plates with the astatic galvanometer. A perceptible current is obtained. After the storage battery has been charged a few times, the current it returns becomes stronger.

SUMMARY.

A magnet is a body which has the property of attracting iron.

The magnetic field is the space through which the attractive influence of a magnet extends.

The like poles of different magnets repel each other; the unlike poles attract each other.

The magnetic needle is a slender bar magnet balanced so that it will revolve in a horizontal plane.

The declination of the magnetic needle is the angle which the needle makes with the geographical meridian.

Induced magnetism is the magnetism which exists temporarily in soft

iron when in contact with a magnet, or when brought within the magnetic field.

The dipping needle is a slender bar magnet suspended so that it will move in a vertical plane, with a graduated arc attached to measure the angle the needle makes with the horizon.

Frictional or static electricity is that produced upon bodies by friction.

There are two kinds of electrification, positive and negative.

Bodies charged with the same kind of electricity repel each other; bodies charged with unlike kinds of electricity attract each other.

An electroscope is an instrument used to determine whether a body is electrified or not.

Positive and negative electrifications are developed equal in amount when two bodies are rubbed together.

Induction is the electrification of one body when another electrified body is brought near it.

A body is insulated when it is separated from other bodies by a non-conducting substance, so that it is able to retain the electricity it acquires.

The electrophorus is an apparatus for obtaining a series of small charges of electricity from a single charge.

A charge of electricity resides on the surface of a body.

The Leyden jar is an apparatus for accumulating by induction charges of electricity.

A voltaic cell consists of two elements and an exciting fluid.

Good conductors are those substances through which electricity passes easily. Non-conductors or insulators are substances through which electricity passes with great difficulty.

Polarization of a cell is any action which tends to set up a current in an opposite direction to the current of the cell.

An electro-magnet consists of a bar of soft iron given magnetic properties by being placed within a coil of insulated wire, through which a current of electricity is passing.

An astatic needle is a combination of two magnetic needles so arranged that the earth's magnetism has no directive influence upon them.

External resistance is the opposition a current of electricity meets in the conductor outside the battery. Internal resistance is the opposition which a current of electricity meets in the exciting fluid of the battery.

An ohm is the unit of measurement of resistance.

A volt is the unit of measurement of E. M. F.

An ampère is the unit of measurement of the strength of the current.

Ohm's law: The strength of a current varies directly as the E. M. F. and inversely as the resistance

In arranging cells, the strongest current is obtained when the internal resistance of the battery is equal to the external resistance of the circuit.

In divided circuits the amount of current that will flow through different branches is inversely as their resistances.

Electrolysis is the decomposition (by the electric current) of compounds in solution.

Magnetic lines of force surround a wire through which a current of electricity is passing.

Lines of force directed alike repel each other; lines of force directed oppositely attract each other.

The north pole of the core of a right-hand helix is at the end where the current leaves the helix.

An induced current is an instantaneous current produced in a closed circuit by the influence of a magnet or another current of electricity.

An induced current is produced by a change in the number of lines of force passing through the space enclosed by a coil of wire.

An increase in the number of lines of force passing through the area enclosed by a coil of wire produces a current in the coil in one direction. A decrease in the number of lines of force produces a current in an opposite direction. The direction of the current depends upon the direction of the lines of force.

An induction coil is an instrument for securing an induced current of electricity of high E. M. F., as compared with the E. M. F. of the battery current.

The telephone involves the principle that the power of carbon to transmit a current of electricity varies directly with the pressure upon it.

The dynamo is a machine for generating electricity by causing, by mechanical means, a change in the number of lines of force that pass through the area of closed coils of electric conductors.

An electric motor is a machine in which an armature is revolved by the action of a current of electricity sent through the machine.

A storage battery is an apparatus which yields a current of electricity due to a chemical change of its constituents produced by a current of electricity.

Questions and Problems.

1. What is meant by amalgamating zinc? Why should the zinc of a voltaic cell be amalgamated?

2. What is an electrode? What, a pole?

3. What are insulators?

4. What is meant by polarization?

5. Which way is the current said to flow in a voltaic cell of copper and zinc, or carbon and zinc?

6. What device is used in Smee's cell to prevent polarization?

7. What are the essential parts of a voltaic cell?

8. Examine the liquid in a gravity cell that has been working two or three days, and tell why it is named a gravity cell.

9. What is an electro-magnet? Name its parts.

10. Upon what principle does the electric telegraph work?

11. Of what use are relays on telegraph lines?

12. Make a drawing of an electric bell on the blackboard, and explain how it works.

13. What effect has a wire conveying a current of electricity upon a magnetic needle when held parallel, and near the wire?

14. What is an astatic needle? Why has the earth's magnetism so little influence upon an astatic needle?

15. State Ampère's rule for determining the deflection of a magnetic needle.

16. What is meant by external resistance? State three conditions that affect external resistance.

17. What is meant by internal resistance?

18. What is an ohm? What is a volt?

19. To what is the strength of a current of electricity due?

20. What is an ampère?

21. State Ohm's law. Write the formula expressing this law.

22. Draw diagrams on the blackboard to show how four cells may be arranged in series, how parallel, and how partly in series and partly parallel.

23. What is the current strength in a circuit with an E. M. F. of 7.5 volts, and a resistance of 9 ohms?

24. Required the current strength in a circuit with an E. M. F. of 11 volts, and a resistance of 33 ohms.

25. What is the resistance in a circuit when an E. M. F. of 9 volts gives a current 1.8 ampères?

26. Required the E. M. F. when the current strength in a circuit is 2.2 ampères, and the resistance 12 ohms.

27. Four cells, each having an E. M. F. of 1.5 volts, an internal resistance of 1.5 ohms, an external resistance of 8 ohms, are arranged in series. Find the strength of the current.

28. Find the strength of the current when these four cells are arranged parallel.

29. What is the strength of the current when these cells are coupled in two rows, two cells being in series and the two rows being parallel?

30. Which is the best arrangement, in series or parallel, of six cells, when the E. M. F. of each cell is 1.25 volts, the internal resistance 1.5 ohms, and the external resistance 20 ohms?

31. What was the strength of the current in Exp. 207, when the cell gave an E. M. F. of 2 volts, and the 50 feet of No. 30 copper wire offered a resistance of 5 ohms?

32. The plates of a cell having an E. M. F. of 1.5 volts are connected by two wires *A* and *B*. The resistance of *A* is 5 ohms; the resistance of *B* is 3 ohms. Find the strength of current in each branch.

33. Make a drawing of the apparatus you set up for electrolysis, indicate the direction of the current by arrows, mark the positive and negative electrodes + and −, and state what element is given off at each electrode.

34. In what direction do the lines of force set round a wire conveying a current of electricity?

35. Under what conditions will parallel wires, conveying a current of electricity, repel each other? Why?

36. Under what condition will the wires attract each other? Why?

37. If you wish to electroplate copper with silver, to which pole would you attach the copper when immersed in a solution of the proper silver salt?

38. A piece of wire is wound around a rod of iron so as to form a left-hand helix. Determine the north and south poles of the core when a current of electricity is sent through the helix. Make a drawing on the blackboard to illustrate.

39. What would be the effect upon a magnetic needle suspended by a silk thread, if a wire carrying a current were placed parallel to the needle and alongside it?

40. What is meant by the terms electro-motive force, and current strength?

41. A piece of copper wire through which a current is passing, decreases in diameter, so that the end where the current leaves is one-third the diameter of the end where the current enters. Is there any differ-

ence in the strength of the current at the two ends of the wire? Any difference in the temperature?

42. How would you determine in what direction a current is flowing in a telegraph wire that passes by your dwelling?

43. Why is a galvanometer with an astatic pair more sensitive than the same coils would be if a single needle were used?

44. Explain why wires conveying parallel currents in the same direction are attracted towards each other?

45. Explain why wires conveying parallel currents in opposite directions separate.

46. Explain the Ruhmkorff coil.

47. How may a current of electricity be induced?

THE X-RAYS.

Electrical Discharges and X-Rays.

In Experiments 221 to 224 we learned that the induced currents produced by an induction coil are capable, like frictional electricity, of yielding sparks. A powerful Ruhmkorff coil (see page 279) is the most convenient means of effecting electrical discharges, as it can be made to send a continuous spark from two to fourteen inches in length. These induced or secondary currents are alternate currents (see Exp. 223), being opposite in direction to the primary current at the making of the contact, and of the same direction with the primary current at the breaking of the contact. The current induced on breaking the contact is, however, of much greater intensity than that on making it, and plays the principal part in electrical discharge.

The electrodes or terminals of the secondary coil are spoken of as *anode* and *cathode*. The anode is the *positive* terminal; the cathode the *negative* terminal with reference to the current induced on breaking the contact.

When an electrical discharge is effected between anode and cathode under ordinary atmospheric pressure, two different light effects may be observed: first, the spark proper

forms a clearly defined straight or zig-zag line between the two terminals, and second, a glow of light of a reddish color surrounds this spark. A conduction of electricity through the air seems to take place in this glow or aureole, while the spark itself is due to the violent breaking through of the current. Heat effects are especially noticed at the negative terminal, and if this consists of a thin iron wire it will begin to glow or even melt away.

These phenomena become more brilliant when the discharge between anode and cathode is effected through tubes containing rarefied gases. Gases when highly rarefied possess a greater conducting power than the same gases under ordinary atmospheric pressure. It is the degree to which the gases have been rarefied that is the important fact, for it is probable that an electrical discharge could not be made to pass through an absolute vacuum.

Tubes containing rarefied gases were constructed by Geissler, a German mechanic, more than a century ago. These tubes, known as Geissler tubes, are of various shapes, and contain rarefied gases through which an electrical discharge can be made to pass by means of two platinum wires sealed in the glass at the two ends and projecting a little into the interior of the tube.

In these tubes the spark proper usually disappears, while the aureole or glow displays color effects of great brilliancy. The light coming from the cathode is usually of a bluish color, while that which comes from the anode is reddish.

William Crookes, an English physicist, made tubes of a globular or pear-like shape. In these Crookes tubes the cathode consisted of an aluminum plate into the centre of which the connecting wire was riveted. The Crookes tube has two aluminum electrode disks. One is used as the cathode, and the other as the anode. Crookes secured a very high degree of exhaustion in some of the tubes he constructed, and found that in reducing the pressure inside the

tube the glow became fainter and fainter, and finally disappeared when rarefaction was carried to about one-millionth of an atmosphere. He noticed, however, at this stage, that a peculiar influence proceeded from the cathode, which, as he thought, consisted in electrified particles projected in straight lines from the cathode. These cathode rays, be it especially noted, may be deflected by a magnet. They also produce heat and fluorescence where they strike the wall of the glass tube or some object placed within the tube.

Hertz, a German scientist, found that the cathode rays penetrated thin sheets of metal placed within the tube, but that the rays did not pass through the glass of the tube.

In order to establish a passage for the rays to the outer air, Prof. Paul Lenard in 1893 made a small window in the vacuum-tube opposite to the cathode, and closed this tiny window with a thin sheet of aluminum. Through this aluminum window the cathode rays easily passed to a distance of about three inches. They could be deflected from their course by a magnet, and like ordinary light they could be reflected, refracted, and polarized ; fluorescent substances held in their path became luminous, and photographic effects were obtained from them.

Professor Roentgen, in 1895, while experimenting with an excited Crookes tube without such a window, made the discovery that the cathode beam was accompanied by a new form of radiance—the X-rays, as he called it. He had his tube covered with a thin mantle of black cardboard, and observed that in a completely darkened room a paper screen washed with barium-platinocyanide lighted up brilliantly and fluoresced equally well whether the side washed with the chemical or the other side was turned towards the discharge tube. This influence emanating from the tube was still observable at a distance of over six feet. He soon found out that these rays passed not

only through cardboard, but more or less through all bodies. They penetrated a bound volume of 1,000 pages, thick blocks of wood, several sheets of tin-foil, a film of aluminum about 15 mm. thick, and thin plates of other metals. Glass plates offered more or less resistance to the rays, according as the glass contained lead or not. When the hand was held between the tube and the screen the dark shadow of the bones was clearly visible within the lighter shadow of the flesh. With increasing thickness and density all bodies became less transparent.

The X-rays are not visible to the eye, but they exhibit a very powerful action upon sensitized photographic plates or films. They cannot be concentrated by lenses, or otherwise refracted or deflected. They produce no heating effect, are incapable of polarization, and cannot, like the cathode rays, be deflected by a magnet. In an ordinary Crookes tube they start from the point at which the cathode rays impinge upon the wall of the glass tube. In order, however, to avoid overheating of the glass by the cathode rays, the so-called focus tubes have been constructed.

In these focus tubes the cathode consists of a concave metallic mirror which focuses the cathodic stream upon a small plate of platinum supported in the centre of the bulb, which may, at the same time, be used as the anode. This arrangement has the further advantage that the X-rays start from a smaller surface, thus giving sharper outlines to the shadows on the fluorescent screen.

An improvement on this tube is Prof. Elihu Thomson's standard tube, where two cup-shaped cathodes and one V-shaped anode are used. By this arrangement the X-rays are made to cover a very large field.

The Fluoroscope.

Instead of Roentgen's original fluorescent screen, an investigator named Salvioni devised a tube over one end of

which he put a cover of cardboard spread with a layer of fish glue and calcium sulphide. When the X-rays fell upon this end it became fluorescent. At the other end he placed an eye-piece so that he might look through this at the shadow cast when a dense object was placed between the Crookes tube and the fluorescent end of the observer's tube.

Mr. Edison later devised an instrument for this purpose, which he termed a fluoroscope. It consists of a dark chamber in the shape of a stereopticon, the front wall of which is made of cardboard coated with fine crystals of tungstate of calcium; this substance was found to fluoresce more brilliantly under the influence of the X-rays than the platinocyanide first used by Roentgen. By placing the hand or the part of the body to be examined close to the screen with the X-rays beyond, one can look through the smaller end of the fluoroscope and see the bones or any foreign body that may be lodged in the flesh. The fluoroscope is designed to obviate the necessity in some cases of making photographs of the part to be examined.

Several theories have been advanced concerning the nature of the X-rays. Roentgen himself was inclined to consider them as longitudinal vibrations of the ether; other investigators tried to explain them as a stream of infinitesimal electrified particles projected from the tube with enormous velocity; others as transversal ether waves of an exceedingly brief period, similar to the rays of the ultra-violet light. None of these theories is as yet proven, but the majority of investigators seem to be in favor of the ultra-violet theory.

Thus far we have only spoken of the Ruhmkorff induction coil as a means of producing the X-rays. We saw that these rays are produced when electrical discharges of a high potential take place in a Crookes tube, the air of which is exhausted to about one one-hundred-thousandth of

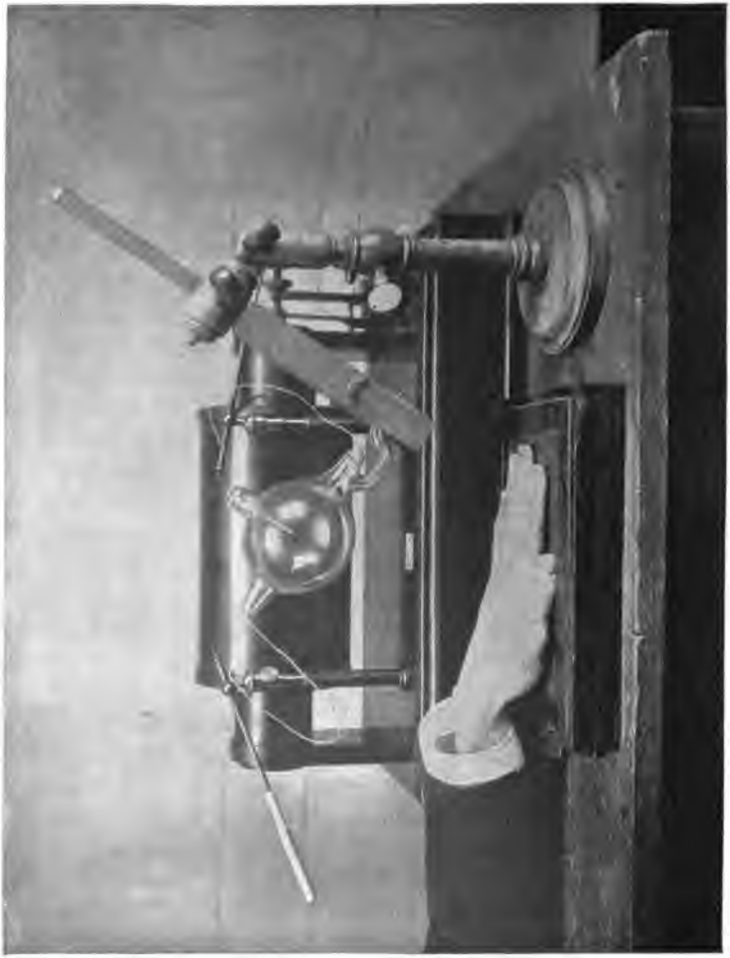

Fig. 277.

an atmosphere. Such discharges may also be obtained from a powerful static machine or from a Tesla coil.

In using a static machine it is sufficient to connect the negative pole of the machine with the cathode of the Crookes tube, and the positive pole with the anode. As a condenser two small Leyden jars may be used, one between the positive pole and anode, and the other between the negative pole and cathode. To regulate the strength of the current, the discharging rods of the prime conductors have to be so adjusted that a dangerous overcharge may pass between them, and thus prevent the Crookes tube from being cracked.

The Tesla coil is, in its construction, similar to an ordinary induction coil. The primary coil contains only a few well-insulated turns of heavy wire. The number of secondary turns is about twenty-four times the number of those of the primary coil. Oil is generally used as insulating medium.

Through the primary coil are passed the rapid discharges from two Leyden jars, which, in their turn, may be charged by the secondary current of an ordinary induction coil, or by a static machine. The results are exceedingly rapid, alternating discharges in the secondary coil. The Crookes tube, in this case, must be fitted with two electrodes that can both act as cathodes.

Photography by X-Rays.

The X-rays have opened a new field to photography. The shadows cast on the fluorescent screen by different objects may be photographed in the usual way. Or the direct rays may be used for the same purpose. In this case a camera is not needed, because the lens has no refractory power upon the rays. It is sufficient to place the object to be photographed on a dry plate wrapped in paper, or placed in an ordinary plate-holder in order to protect it from other

FIG. 278.

sources of light. The time of exposure varies, according to the opacity of the object and to the efficiency of the apparatus, from a few seconds to half an hour and more.

Fig. 277 shows a common arrangement of apparatus for photographing.

The muscles and other soft tissues of the body obstruct the passage of the rays very little and so give light shadows on the plate, while the harder tissue, the bones, obstruct the passage much more and so give darker shadows. See photograph of frog, Fig. 278. Bullets, pins, and other dense foreign substances may by this means be located, and after such location, be easily removed by the surgeon.

Fractures of the bones and other malformations are revealed by a photograph made by the X-rays. And broken bones near the joints may be distinguished from dislocations, in cases where swelling would prevent examination by the surgeon.

Whatever revelations the X-rays may make in the future for pure science, its practical applications in the domain of medicine give guiding and definite information where formerly there was only conjecture.

The Roentgen rays, moreover, are likely to cause a revolution in electric lighting. Edison has constructed a lamp in which the fluorescence produced by the Roentgen rays is used as a source of light. This lamp consists of a Crookes tube whose inner walls are coated with a highly fluorescing matter. When excited in the ordinary way by a powerful induction coil it emits a mild, but effective, light, which may be used for illuminating purposes like any other source of light.

APPENDIX.

§ 1. **To make a Pair of Scales.**—The parts and dimensions of a pair of scales are shown in the accompanying sketch. The base and upright pieces are made of pine. The beam in the scales represented in Fig. 279 was made of a maple ruler planed off at the edges. *A* is a piece of sheet iron or brass. A piece of knitting needle driven

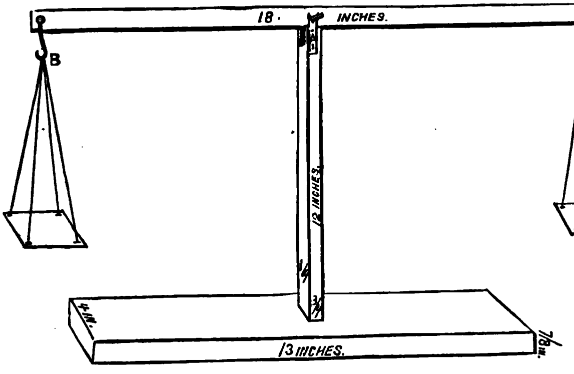

Fig. 279.

through the beam rests in the V of the iron pieces. The scale-pans are constructed so as to be removed from the wire hooks. In making the scales, see that all the bearings are very smooth.

§ 2. **To cut Glass Tubing.**—Lay the tube upon the table, and give a strong, steady cut with a three-cornered file. If the tube is large and thick, continue the cut around the tube. Then, holding the tube in the hands, with the cut between the thumbs, press outward with the thumbs, and the tube will break off as desired.

To bend Glass Tubing.—Warm gradually that part of the tube that is to be bent, by passing it through the flame of an alcohol lamp or Bunsen's burner. Then hold the tube constantly in the flame just above the blue cone of the flame. As soon as the flame burns yellow, and two or three inches of the tube are found to be soft, gently bend the tube to the required shape.

If an ordinary gas flame is used and the tube held lengthwise of the flame, a less abrupt bend can be made.

To smooth the Ends of a Glass Tube.—Warm the end of the tube by passing it through the flame. Then hold the tube obliquely in the flame and slowly turn the tube. When the flame begins to be colored yellow by the sodium of the glass, the edges are rounded.

To close the End of a Glass Tube.—Heat the tube gradually and then hold in the flame, turning the tube till the end is closed. Or, hold the end in the flame till it becomes soft, and then pull the end out by touching it with another piece of glass. The glass will be drawn out to a long thread. Break off this thread, and hold the small end in the flame. The small opening will soon close.

To bore a Hole in Glass.—Make a spot on the glass with ink where the hole is to be drilled. Moisten the glass with a drop of turpentine and add a few particles of camphor. Break off the end of an old round or three-cornered file, so that it will have a cutting edge. Take the file in the hand, and bore upon the spot marked. Do not press too hard. Break off a small particle from the end of the file from time to time.

Water may be used instead of turpentine and camphor.

Large holes may be drilled by using a piece of brass tubing and emery powder moistened with water.

To cut off the Bottom of a Bottle or to cut a Lamp Chimney in two.—File a little groove in the glass, and touch this groove with a hot iron or a piece of lighted "punk" till a crack is started. Then, by holding the hot iron just ahead of the crack, it may be led in any direction. Rub the edges with a file to smooth them, or, what is better, use a whetstone upon them.

§ 3. List of Apparatus.—The following articles may be ordered of Messrs. Eimer & Amend, 209 and 211 Third Avenue, New York, or other dealers in chemical and physical apparatus and chemicals, at the prices here given :

1 ounce pure rubber tissue	$ .25
3 rubber stoppers, two holes each, No. 4, No. 7, and No. 10 .	.75
5 feet rubber tubing (¼ inch inside diameter), catalogue No. 8,012	.50
1 eight-ounce flask	.15
1 four-ounce flask	.12
Ignition tube	.15
2 test-tubes	.10
½ pound (16 feet) glass tubing (¼ inch outside diameter) .	.25
1 pound mercury	.75
1 Fahrenheit thermometer (270°, paper scale inside of tube) .	.90
(A Fahrenheit thermometer, 300°, engraved on stem, costing $1.70, is rather more convenient.)	
Wire gauze (fine)	.25
Crown glass prism (four-inch)	.25
2 bar magnets (eight-inch)	1.50
Platinum foil (1 square inch)	.50
Spring balance	.50

The following may be ordered of J. H. Bunnell & Co., 76 Cortlandt Street, New York, or any dealer in electrical supplies. The prices given are at New York rates :

2 gravity batteries (not crow-foot pattern)	1.50
2 pounds of copper sulphate (blue vitriol)	.20
1 pound bichromate of potash	.25
3 zinc rods (Le Clanché cell pattern)	.20
3 electric light carbons (uncoppered, 12 inches by ⅜ inch) .	.25
1½ pounds No. 16 copper wire (double cotton covered) . .	.90
½ ounce No. 30 German silver wire (single cotton covered) .	.15
½ pound No. 30 copper wire (double cotton covered) . .	.55
2 ounces No. 20 copper wire (single silk covered, about 40 feet)	.25
1 ounce No. 27 copper wire (single silk covered)	.15
Amount forward	$11.32

Amount forward	$11.32
The hollow cylindrical cross (Exp. 59), 6 inches long, 1¼ inches in diameter, arms projecting out 1¼ inches, can be made by any tinsmith, and ought not to cost more than	.30
Tuning-fork	.25
Sulphuric acid	.13
Miscellaneous	3.00
	$15.00

No account is made of strips of wood, bottles, pieces of lead, strips of old sheet copper, and similar articles that are always at hand.

§ 4. **How to make a Siren.**—Cut out of smooth, stiff cardboard a disk 10 inches in diameter. From the centre draw concentric

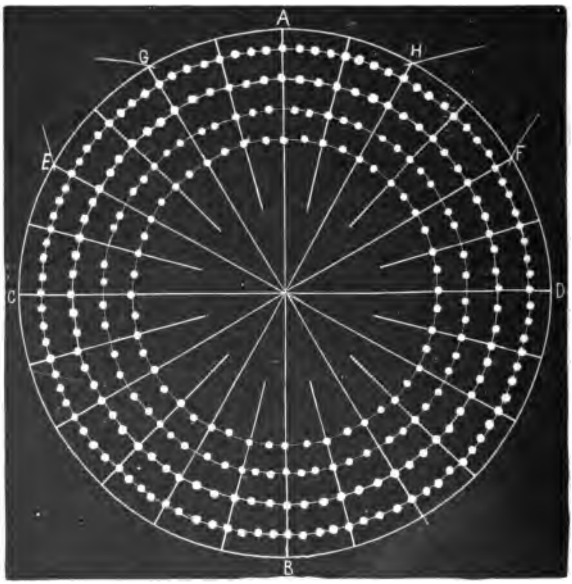

FIG. 280.

circles, having for their radii 3⅜, 3¾, 4⅛, and 4½ inches respectively. Next draw two diameters *A B* and *C D* (Fig. 280), at right angles to

each other. From A as a centre, with a radius of 5 inches, draw the arcs E and F. From D as a centre, with the same radius, draw the arc H, and from C draw the arc G. From the points where each of these arcs cuts the circumference draw diameters. Six diameters have now been drawn. Midway between these draw six other diameters as shown in Fig. 280. Now punch smooth holes through the cardboard, as shown by the figure, 48 holes in the inner circle, 60 holes in the next, 72 holes in the next, and 96 holes in the outer circle.

Cut out of wood a wheel 1¼ inches in diameter, and groove the wheel so that it may be used as a pulley. Tack the cardboard disk upon this small pulley wheel, centre for centre.

Make a large pulley wheel 12 inches in diameter, as shown in Fig. 127, page 154. In place of the handle A, use a spool fastened to the pulley wheel by a screw.

Complete the apparatus, as shown in Fig. 127, by driving a wire nail through the centres of each of the pulley wheels into the upright strip of wood. Let the centres be 21 inches apart. Put on a tight cord for a pulley band, and revolve the siren disk.

How to make a Sonometer.—The sonometer (Fig. 128) consists of a wooden box 4 feet long, 6 inches wide, and 2 inches deep. It should be made of wood not thicker than half an inch. A hole should be bored in the top about 2 inches in diameter.

Very good results can be obtained without this sonometer, by following the suggestion at the foot of page 157.

§ 5. **How to make a Porte Lumière.**—Cut out a board A A (Fig. 281) ten inches square and about three-quarters of an inch thick. Draw a line through the middle from end to end. On this line, three and five-eighths inches from the top, bore a hole H one and a half inches in diameter.

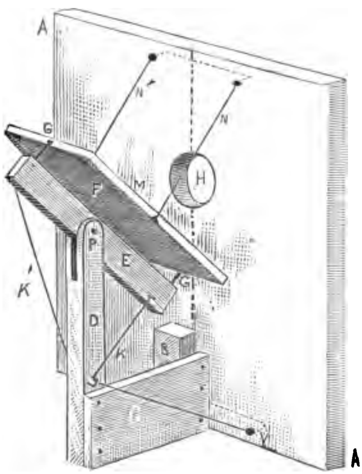

Fig. 281.

Next cut out the following pieces of wood : B, $2\frac{1}{2} \times 1\frac{1}{4} \times \frac{3}{4}$ inches ; C, $4 \times 2 \times \frac{1}{2}$ inches ; D, $5\frac{3}{4} \times \frac{3}{4} \times 1$ inch ; E, $6\frac{1}{2} \times \frac{3}{4} \times \frac{3}{8}$ inches ; F, to which the mirror is to be fastened, $6 \times 3 \times \frac{1}{4}$ inches.

Nail B flat upon A A, making the end flush with the lower end of the board. To this cleat nail C, as shown in the figure. In the end of D, cut a slit three-eighths of an inch wide, and one and a half inches deep. At the upper end of this insert E, fastening it at its central point with a wire nail P for an axis. Secure D to C, as shown in the figure.

Cut off the heads of two wire nails G G, and one inch from the point bend them at a right angle. Make a hole in the centre of each end of the piece of wood F, and insert the shorter arms of the nails. Then drive the longer arms of the nails into the upper edge of E, so that the mirror board F will turn easily.

On each side of D drive a small staple, as shown in the figure. Make a small hole V two inches from the central line. Fasten a string K to E one inch from the end, pass it through the staple, through the hole V, along behind the board, as shown by the dotted line, through a corresponding hole and staple on the other side, and up (K') to the other end of E. This string should be drawn tight. By moving it back and forth behind the board, the mirror may be made to turn on its axis P.

At the top of A A, one and a half inches each side of the central line bore two more holes. Secure a string N N' to the centre of one side of F, put it through one hole, pass it behind the board, then put it through the other hole, and fasten it to the other side of F. By moving this string back and forth, the mirror may be made to turn on its axis G G.

Make a dark shutter to fit any window into which the sun shines, and put the *porte lumière* in a square hole cut to receive it in the dark shutter. If there are other windows in the room, darken these so that no sunlight can come in.

By moving from the inside the strings of the *porte lumière*, a horizontal beam of sunlight may be directed through the hole H.

A piece of tin with holes of different sizes drilled through it may be placed over H when it is necessary to make smaller the aperture through which the sunlight comes.

§ 6. **How to make a Bichromate Cell.**—Cut each of the three electric light carbons (see § 3) into two parts. File a little groove around the top of each, twist the end of a piece of copper wire about six inches long around the carbon in the groove. Make a mould

of wood or plaster of paris, and run lead around the carbon where the wire is wound (see *L*, Fig. 282). Cut out a strip of wood long enough to extend across the top of a tumbler or other glass vessel that may be used, bore three holes through this piece of wood, and drop a carbon into each outer hole. Between the carbons place a rod of zinc (see § 3), as shown in Fig. 282.

There should not be more than half an inch between the zinc and the carbon.

The exciting fluid is made by pouring five fluid ounces of sulphuric acid into three pints of cold water, and, when this has cooled, adding six ounces (or as much as the solution will dissolve) of pulverized bichromate of potash (see § 3). Be careful to stir well. Pour this solution into the glass vessels that are to be used for battery jars, and put in the carbons and zinc. When this cell is not in use, lift the elements out of the exciting fluid.

Three cells can be made of the three carbons and three zincs mentioned in § 3.

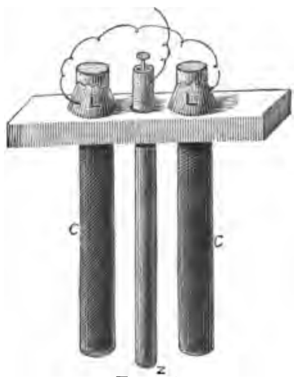

FIG. 282.

§ 7. How to make a Small Magnetic Needle.—Heat a piece of watch-spring to redness, and allow it to cool. Then cut off a piece half an inch long, and straighten it. In the centre make an indentation with a sharp punch. Thrust a pin through a piece of cigar box half an inch square for a standard. Put the indentation made in the piece of watch-spring upon the point of the pin, and see whether the piece of watch-spring will balance. If it does not, then file off one end till the piece balances exactly. Now magnetize the piece. Should there be any dip, file off the needle till it balances exactly.

Home-made Connectors.—Connectors that will answer every purpose may be made by taking a piece of sheet copper one inch long, and three-eighths of an inch wide, and drilling a hole in each end to carry a small brass screw. Put the piece of copper upon a small strip of wood, place a copper washer under the head of each screw, and wind the wires around each screw respectively. Then

drive the screws into the wood through the holes in the strip of copper. See that the wire is held firmly between the washer and the strip of copper, and a good connection will be formed.

Current Reverser.—Draw a square one inch on a side upon a piece of wood. At each corner of the square bore a quarter-inch hole to the depth of half an inch. Fill each hole with mercury. Next make of insulated copper wire two staples of such a length that they may be used to connect any two holes of the square either diagonally or along the side. Remove the insulation from the ends of these staples.

Bend the ends of the wires from the battery down at right angles a quarter of an inch, and dip these into two holes of the square numbered 1 and 2, Fig. 283.

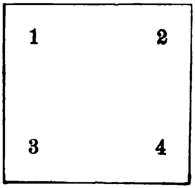

FIG. 283.

In like manner bend the ends of the wires from the circuit, and dip these ends into holes 3 and 4.

Now by connecting with one staple, holes 1 and 3, and with the other staple, holes 2 and 4, the current is not reversed in the circuit. But by connecting with one staple, holes 1 and 4, and with the other staple, holes 2 and 3, the current is reversed in the circuit.

§ 8. **How to make a Galvanometer.**—Cut out of a block of wood a frame *A A*, Fig. 284, four inches long, two and three-quarters inches wide, and three-eighths of an inch thick, with the hole three inches by two inches. Make the outside edges of the frame round, as shown in the figure.

Around this frame, about one and five-eighths inches from the end, wind as evenly as possible forty-five turns of No. 27 insulated copper wire, in such a manner that there will be in the coil *B B* fifteen strands of wire in width and three layers in thickness. Bind this coil together with a piece of string *K*, and carrying the wire on in the same direction, make another similar coil *D D*, one-eighth of an inch from the first. Secure the ends of both coils by tying them, or by means of double-pointed tacks of brass wire driven into the wooden frame.

Give the wire a thick coat of shellac to hold the strands firmly together. Next, pass a sixteenth of an inch brass wire through a cork *C*, and bending the ends *G H* down at right angles, as in Fig. 284, drive them into the upper side of the frame between the two coils. Pass a smaller brass wire *E*, one and a half inches long, vertically through the cork *C*, and make a loop at each end.

Place two needles one and five-eighths inches long, side by side, with their points together, and holding them in this position magnetize them equally and as strongly as possible with a bar magnet. Remove the insulation from a piece of No. 30 copper wire *W* (Fig. 284), and fasten the needles so as to form an astatic pair five-sixteenths of an inch apart in the position indicated, by twisting the wire a few turns about each needle. In one end of this wire make a small loop, and suspend the astatic pair from the wire *E* by a piece of untwisted silk, *T*. By turning the wire *E*, and moving it up or down, the needles

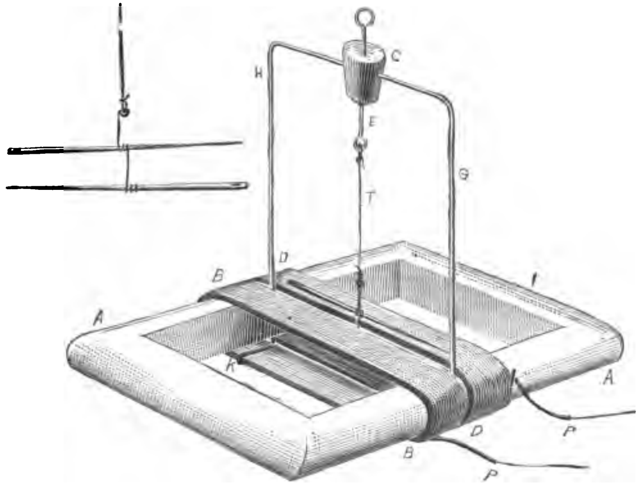

FIG. 284.

may be brought into the proper position. One needle should be above the coils, and the other below the upper turns of the coil. The needles should be parallel to each other and to the edges of the coils, and they should turn without obstruction. In order to make the wire *W* (Fig. 284) pass through the centre of the narrow slit between the coils, the apparatus may be balanced by pieces of wood or paper placed under the corners of the frame. In order that the needles may not be moved by currents of air, the galvanometer should be placed in a box with a glass cover; the points of attachment *P P* should pass through the sides of the box.

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